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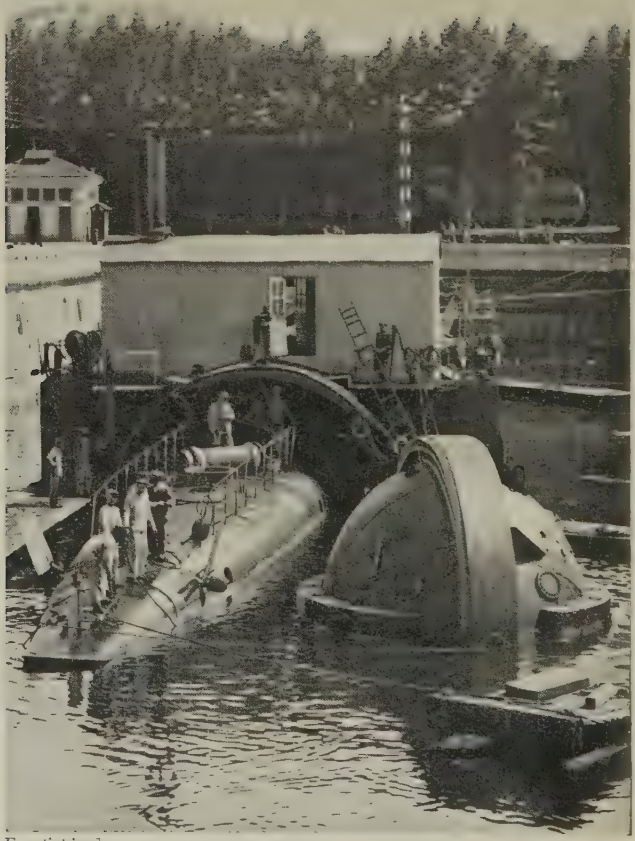


Frontispiece]

TESTING THE SUBMARINE

The underwater vessel is entering the novel Laurenti dock, the hinged globular door of which may be seen at right.

DEPARTMENT OF EDUCA

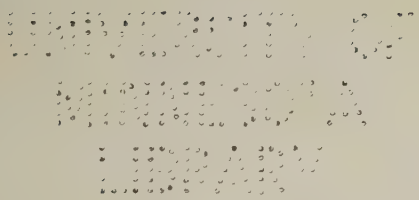
SUBMARINES

THEIR MECHANISM AND OPERATION

BY

FREDERICK A. TALBOT

AUTHOR OF
"AEROPLANES AND DIRIGIBLES OF WAR," ETC.



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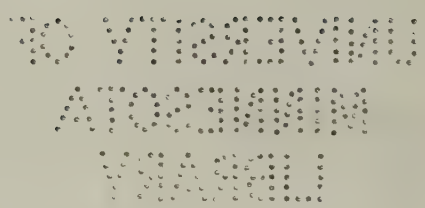

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PREFACE

It is safe to assert that few fighting ships are of such fascinating interest or so generally misunderstood by the average reader as the submarine. This is due to the fact that the underwater fighting vessel, as we know it to-day, is the product of contemporary thought and experiment. Its development has constituted a highly specialized and secret branch of naval engineering prowess and skill—one in which only a comparatively few workers have participated.

The present volume is neither a history nor a technical treatise, despite the circumstance that the subject embraces some of the most complex ramifications of engineering and scientific technics. It is written essentially for the general reader who desires to acquire a rudimentary knowledge concerning the type of vessel whose exploits have become a theme for animated discussion and conversation. It is a popular exposition of the principles of design, construction, operation and possibilities of this craft. Technical details have been resolved into language which may be readily understood.

In the preparation of this work I have been courteously assisted by many of the most brilliant minds which are intimately identified with the evolution of the submarine. I am especially indebted to the Electric Boat Company of New York, the Lake Torpedo Boat Company of Bridgeport,

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Connecticut, U.S.A., the editor of the *Scientific American*, certain engineers to whom acknowledgment is extended in the text, and to others whose names cannot be specifically mentioned for various reasons. So far as the German submarine is concerned, the greater part of the information relating thereto was placed at my disposal by the Krupp Company of Essen.

While the volume deals more particularly with the American submarines, for reasons which are obvious, the subject suffers little from such an apparently narrow line of treatment. The submarine as we know it to-day is essentially the product of American brains. Other Powers acquired the American ideas but developed distinctive types along individual lines to meet national requirements. At the same time the general and fundamental principles, together with the governing methods of operation, remain.

The submarine is still in its infancy. The searching test of practical application has revealed many of its possibilities and shortcomings, and doubtless further striking evidences of its potentialities will be forthcoming before the present momentous conflict has run its course.

FREDERICK A. TALBOT.

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CHAPTER I

EARLY EXPLOITS OF THE SUBMARINE

No type of vessel in the present naval war has played so large a part or claimed such world-wide attention as the submarine. So far as the prevailing impression is concerned, this craft appears to be possessed of almost supernatural powers and to enjoy an uncanny immunity against all measures which may be attempted to compass its capture or destruction.

But this character of invulnerability and omnipotence with which the underwater fighting machine has become invested is due, for the most part, to the highly imaginative and romantic writer of fiction. The erroneous impression thus created has become firmly rooted in the average mind for the simple reason that the cool, calculating, scientific worker has preferred to toil in secrecy, and has never attempted to dispel the distorted and fanciful views which prevail concerning this craft and its possibilities.

The average individual regards the submarine fighting vessel as a product of the present century; but this is not the fact. Indeed, the submarine is practically as old as the sailing ship. Centuries ago the idea of moving underwater was receiving

the attention of brilliant minds who concerned their energies and fortunes upon the perfection of ways and means of travelling beneath the surface of the sea. Certainly the majority of these efforts were fantastic in conception and crude in design, but they serve to illustrate the fact that, contrary to general opinion, the idea of the submarine is far from being a product of our highly trained contemporary civilisation and scientific knowledge.

During the early months of the year 1915 the ephemeral predatory successes of the German submarine fleet created extraordinary uneasiness among the timorous of the British nation. Yet this was by no means a novel or isolated experience. More than one hundred years ago a similar state of nervousness was manifested among the British people. This was entirely attributable to the circulation of wondrous stories and rumours concerning the assiduous attempts which were being made to introduce underwater fighting vessels against us : a method of warfare which the British fighting dogs of " eighteen-hundred-and-war-time " stigmatised as " sneaking." These stories sprang from the activities of an enterprising American, David Bushnell. Bushnell has often been described as the " Father of the Submarine," a title to which he has no claim, seeing that the idea of the submarine, as we know it to-day, is essentially British, having been elaborated by Mr. J. Day, who was drowned in a submarine boat of his own

design in Plymouth Sound 1774. At the same time, however, Bushnell deserves every credit for what he advocated and accomplished, because he set the train of thought in this field fairly in motion. While at college he conceived the idea of a submarine fighting ship, and devoted his energies and private resources towards the perfection of his great scheme. He was, however, doomed to experience bitter disappointment, for the reason that his submarine, like the *Great Eastern* built by Brunel, was in advance of its time.

The Bushnell submarine, described by its creator as a "turtle ship," from the fact that it bore a close resemblance to this creature of the sea, attracted considerable attention, doubtless because of its novelty. Virtually it comprised two turtle-shell-shaped structures. It differed from the modern craft in that its longitudinal axis was disposed vertically; in other words, it stood upon one end in the water. The upper space between the two shells carried a small conning tower, which might have been the head of the turtle.

Naturally the craft was very small, being designed to carry only one man. The conditions within were by no means enviable. There was no illumination whatever, the one-man crew being absolutely in darkness when submerged, while the quarters were exceedingly cramped. The air-storage facilities were of the poorest, but they were ingeniously utilised and carried a supply which allowed the

craft to remain underwater for the space of half-an-hour.

The basic principles of this vessel were broadly identical with some of those prevailing to-day. The vertical position of the boat was maintained by a false keel of lead weighing 200 pounds, which was attached to the lower end. This weight could be detached when desired, being connected to a length of chain which could be paid out for about eight fathoms and which could be wound in when the craft regained the surface. Submergence was achieved by the admission of water into the ballast tanks, while two pumps enabled the water to be discharged when it was required to return to the surface. On the conning tower were valves which worked automatically. When the vessel was moving awash these valves opened to admit fresh air, but directly the craft descended they closed, also automatically. Propulsion was effected manually by means of an oar, while a second oar facilitated movement in the vertical plane. A rudder was provided for steering. The equipment was completed with a barometer, for indicating depth of submergence, and a compass, illuminated with phosphorus, to enable the operator to grope about under water in the darkness.

The most conspicuous feature, however, was the offensive armament. This was a detachable magazine, virtually a torpedo, which was carried upon the upper part of the little boat. Ordinary

powder constituted the explosive, and the charge was fired by means of a clockwork detonator. The inventor's idea was to approach his objective while the enemy vessel was riding at anchor, preferably under cover of darkness, to drive a screw into the hull of the quarry, attach the torpedo thereto, and then to steal away to await events, the clockwork mechanism being set as desired and permitting a sufficient length of time to elapse to ensure the submarine getting clear of the danger zone.

During the American War of Independence a determined effort was made to turn this fiendish weapon of war to profitable account. The British man-o'-war *Eagle* was lying off Governor's Island in New York Harbour. Bushnell's brother, who had become expert in the operation of the submarine, was to make the attempt to torpedo the British warship, but he was taken ill, and another man, Ezra Lee, who was familiar with the craft, was entrusted with the task. Lee worked the submarine to a point beneath the hull of his objective and attempted to drive the screw, to which the torpedo was to be attached, into the warship's hull. But he happened to strike some part of the *Eagle's* hull which effectively frustrated his designs: the screw could not be sent home.

In his disappointment Lee appears to have been seized with a fit of nervousness and bungled badly. In attempting to discover a more susceptible part of the *Eagle's* hull he lost track of

the warship altogether. After groping about in the darkness of the water for some time, he came to the surface. Dawn was breaking and, fearful of discovery, he made off. As he was passing Governor's Island he fancied that his whereabouts had been discovered by the watch on board the warship, and, dreading attack, he hurriedly discarded his torpedo, the clockwork mechanism of which was ticking merrily. The torpedo was caught by the tide and current, and finally exploded some 90 feet astern of the *Eagle*. The explosion and column of water which was thrown into the air thereby created consternation amongst the crew of the warship, bringing home to them the fact they had narrowly missed a terrible fate. This experience prompted the commander to maintain a keener look-out, and to keep his vessel constantly on the move.

Lee hastened back to his parent ship, which was lying higher up the Hudson River, and regained her in safety. Two further attempts were made to torpedo the *Eagle* by means of Bushnell's submarine, but both proved abortive. This " submarine liveliness " in New York harbour stirred the British to action. The submarine's parent ship was discovered, and as it became known that she was harbouring a dangerous little craft aboard, she was pursued and promptly sunk. Bushnell subsequently recovered his famous little boat, but, finding it impossible to prosecute his task any farther, he

abandoned it with keen disappointment, and proceeded to France, where he lived for many years. Upon his return to the United States he practised medicine, but under an assumed name, and amassed a large fortune. He never returned to the improvement of his original idea. In fact, the circumstance that the amiable doctor was in reality David Bushnell of previous submarine fame never became known until after his death, when his identity was revealed in his will.

The menace of the submarine was again brought home to the British nation during the Napoleonic wars. Robert Fulton, the famous American engineer, left England for France, where he aroused considerable attention with designs for torpedoes detonated by clockwork, and for the use of these in conjunction with a submarine boat. It is very evident that Fulton had been attracted to this field of endeavour by the experiments of Bushnell, and he sought sedulously to obtain the co-operation of the French nation by playing upon the prevailing trend of feeling. He had perfected ways and means of challenging the British command of the sea, or, as he termed it, "naval tyranny." His submarine, which carried two men, was christened the *Nautilus*. It was manually operated, the propeller being revolved by a hand wheel, the power thus generated being transmitted through shafting to a small propeller.

But Fulton failed to arouse the enthusiasm

which he considered that his ingenuity deserved. His invention was regarded in the manner of a sensation, and the public followed its evolutions in the Seine with an interest similar to that which they would have manifested towards a cowboy subjugating a bucking broncho. The Government refused to regard the idea seriously, the Minister of War, in fact, displaying ill-disguised hostility towards the scheme. But Fulton was by no means discouraged. He approached Napoleon, who was then consul, for assistance and protection. The "Little Corporal" turned the suggestion over to Volney, Laplace and Monge, who went into the project thoroughly. In due course they presented their report to Napoleon and it was so favourable that Fulton was made a grant of £250—$1,250—for further experiments, which he was urged to complete with all speed.

The *Nautilus* differed from Bushnell's craft in that the longitudinal axis of the cigar-shaped boat was in the horizontal plane. It was built of wood sheathed with copper. Near the pointed prow was a small dome, corresponding to the conning tower of the modern vessel, and fitted with ports. It had an over-all length of 21 feet 4 inches, and for travelling awash was fitted with a mast and sail. When it was desired to submerge, the mast was stepped, water was admitted into the ballast tanks, while air was compressed within the remaining space of the interior by means of

pumps. Consequently, descent was automatic. When it was desired to ascend, the water was pumped out, when, of course, the boat, owing to its buoyancy, came to the surface.

After submitting the *Nautilus* to prolonged experiments in the Seine, the results of which he considered to be eminently satisfactory, Fulton started in his boat for Brest. It is related that during the journey he threw the gunners of the forts which he passed into fits of consternation by periodically diving and re-appearing. On June 3, 1801, he carried out a series of tests in the roadstead of Brest, succeeding, among other things, in attaching a torpedo to a pontoon, which was blown to atoms by the subsequent explosion. On another occasion he rested upon the sea-bed for a period of five hours.

The experiments were admitted by the French marine authorities to be diverting and interesting but far from conclusive. They demanded a more effective and practical demonstration of its possibilities and destructive qualities. To this end Fulton waited patiently for some time for the appearance of a British man-o'-war, which he was confident he would send to the bottom, but no British craft appeared.

The result was that public enthusiasm and official interest, after the first feeling of novelty had passed, dropped to zero. Napoleon, with his characteristic impetuosity, lost complete faith in

the invention, since it had accomplished nothing tangible, and regarded Fulton as one of the many charlatans and adventurers who endeavoured to prey upon him at the time. When Fulton applied for further financial and other assistance and favours he received a rude awakening. His overtures failed to receive a moment's consideration, although his requirements certainly were modest. He sought the payment of £1000—$5000—from which the initial sum he had received was to be deducted, for the invention, together with the bestowal of the title of a belligerent. The latter was a crafty move, since such a grant would have given him permission to rove the seas and to prey upon British commerce, while at the same time, in the event of capture, he and his crew would have been protected against an ignominious fate—hanging from the yard-arm as pirates.

But Fulton's star, so far as France was concerned, had waned. The French Minister of Marine vehemently protested against the extension of such a title to Fulton, and his attitude was supported whole-heartedly by Caffarelli, the Maritime Prefect of Brest. This method of fighting had never appealed to them : it savoured too strongly of the assassin. Their protests won the day : Fulton's invention was discarded unanimously.

Fulton was bitterly disappointed at this turn of events, which he had never for a moment expected. Forthwith he returned to Britain and offered his

invention to this government. Whatever other attributes Fulton may have possessed he was certainly void of all scruple, and was animated by sheer mercenary motives. Having failed in his efforts to ravage British commerce, he now went over to the opposite camp and expressed his readiness to establish British marine supremacy more firmly than ever by means of his invention. But he had a tender thought for the safety of his own skin: he assumed the pseudonym of "Mr. Francis" in order that the French might not be able to discover his identity. He succeeded in gaining the ear of Pitt, who became so impressed with the American engineer's claims as to repose a blind faith in him, stating that "such a system, if successfully introduced into practice, could not fail to annihilate all military marines."

But my Lords of the Admiralty refused to see eye to eye with the Prime Minister, although the former finally were persuaded to permit "Mr. Francis" to make one practical test with his torpedoes. To this end, what has become known as the "catamaran expedition" was organised. Catamarans of coffin shape, made of wood lined with lead, and charged with explosive to be detonated by timed clockwork mechanism, were towed and cast adrift among the French shipping lying in Boulogne Harbour. The raid was made under cover of darkness, Fulton suggesting that the torpedoes would foul the anchoring hawsers and explode in

due course. But this novel attempt to spread disaster among the French vessels proved a miserable fiasco. Some of the torpedoes exploded, but the damage wrought was infinitesimal. My Lords of the Admiralty were so disappointed at the fruits of the expedition that they, in turn, lost complete faith in Fulton and his claims, despite his lengthy explanations of the whys and wherefores the torpedoes did not explode. His whole system was discredited. Strange to say, Pitt still maintained his faith in the idea of "Mr. Francis," and in the effort to bring official opinion to his way of thinking he arranged for the torpedoing of the brig *Dorothea* off Deal.

Although the Admiralty authorities did not abate their scepticism one tittle, they humoured the Prime Minister and witnessed the demonstration. A torpedo containing 170 pounds of explosive was fired under the brig and sank her. It is stated that this spectacular demonstration brought home the power of the torpedo and submarine explosion to the British mind for the first time, and that it was responsible for the creation of a feeling of extreme anxiety in official minds which hitherto had been hostile. This, however, we may be permitted to doubt. Any one who is conversant with the attitude of My Lords of the Admiralty, which is traditional, would consider with infinite amusement the possibility of striking terror into their hearts. Yet this knowledge did not suffice to prevent the

dissemination of rumours that Fulton had been offered a large sum of money to suppress his inventions, and that he had disposed of his secrets to the British Government for a substantial pecuniary reward.

Whatever the subsequent negotiations, one fact remains: Fulton shortly afterwards returned to his homeland, where he introduced his ideas to the American government. The latter, however, proved to be quite as hostile and as incredulous as the French and British authorities had been towards the project. He was ridiculed mercilessly, and when he made several efforts to blow up a vessel in New York Harbour, and failed completely in the task, his discomfiture was complete.

During the second war of American Independence, H.M.S. *Ramilles*, while lying off New London, was assailed upon several occasions by a submarine vessel, which strove to attach torpedoes to her hull. Fortunately the attempts failed, but they caused such alarm among the crew of the warship that the commander took advantage of a time-honoured precedent to secure protection. He kept a large number of prisoners on board, who, he announced far and wide, would certainly go to their doom as well as the crew if the ship were sunk. This precaution proved successful. The submarine tactics were abandoned, for the simple reason that the popular outcry which was provoked by the threat of the commander of the *Ramilles* stirred the citizens

to such a depth that an extensively signed petition was presented to the authorities denouncing these underwater fighting methods and insisting upon their instant discontinuance. The submarine which participated in this work, however, is generally believed to have been one of Fulton's vessels.

But the most daring expedition ever suggested in these early days of the submarine was that proposed for kidnapping Napoleon from St. Helena. It is stated that powerful sympathetic interests approached a certain British mariner, Captain Johnson, who is said to have been a notorious smuggler, and, by the offering of a tempting reward, prevailed upon him to assent to making a dash for the surreptitious rescue of Napoleon from his island prison by means of a submarine.

A huge sum of money was promised if the attempt should prove successful, while £40,000—$200,000—were to be paid over on the day the boat was completed. The British captain agreed to the proposals, and his programme certainly was startling. Apparently he was to be carried, together with his submarine, by ship to a certain point. Here the submarine was to be lowered overboard, and therein Captain Johnson was to proceed underwater to the island, timing his arrival off St. Helena at dusk. There he proposed to await his opportunity and to proceed underwater under cover of darkness to a lonely part of the shore where a landing could be effected. An emissary was then to be sent to Longwood, to

apprise the prisoner that an avenue of escape was available and was awaiting him. Napoleon was to proceed cautiously with his guide to the rendezvous. There the submarine was to be boarded and the boat was then to steal away in the manner of its arrival—submerged—until it had reached a safe distance from the island, when it was to travel awash to the waiting ship. The construction of the boat was begun, but on the day when the work on the outer shell of copper was to be started the desperate enterprise was rendered unnecessary owing to the death of the august prisoner. However, the submarine was completed and subjected to trial in the Thames. It would have been a somewhat ironic circumstance if Napoleon, who had ridiculed the submarine several years previously, had depended upon this craft for his escape. It was fortunate for the peace of the world at large that the Arbiter of Fate intervened.

CHAPTER II

THE COMING OF THE MODERN SUBMARINE

ALTHOUGH the development of the submarine during the closing decades of the eighteenth and the opening years of the nineteenth centuries may be said to have proved abortive, since the idea failed to receive sufficient recognition from any of the Powers to lead to its adoption as a definite naval arm, yet inventive effort was by no means killed. During the fifties of the past century there was a pronounced revival in this field of endeavour, mainly through the perseverance of a German experimenter named Bauer. This inventor, however, could not hope to profit from his invention in his native land, since the latter had not dreamed of naval supremacy at that time. Consequently he proceeded to Great Britain and laid his plans before the Admiralty, thinking that here lay the most probable market for his brains and handiwork.

Once again the idea of the submarine was regarded with indifference, although the Government went so far as to appoint a special committee of practical engineers, among whom was Brunel, to investigate its proposals and claims. But their

report was not pronouncedly favourable, whereupon Bauer, in the heat of disappointment, assumed a remarkable attitude. He accused Great Britain of stealing his designs and endeavouring to deprive him of the honour to which he maintained he was entitled. As a matter of fact, Bauer's plans proved impracticable. An experimental vessel was actually built, but it failed to fulfil the inventor's expectations. Recently a full-sized craft was built according to Bauer's designs and has been placed in a museum in Germany.

The outbreak of the Crimean War once more served to draw attention to underwater fighting, and a vessel was built in this country, but again failure was encountered. In France, too, the efforts of inventors had been attracted to this field, a vessel being built according to the designs of Commandant Bourgeois, who was an accomplished scientific naval officer. But his vessel proved to be no more successful than those which had gone before.

The first occasion upon which the possibilities of the underwater craft as a fighting unit were brought home in a forcible manner was during the Civil War of the United States. The Southerners, groaning under the blockade which was maintained by the vessels of the Federal faction, decided to make a bold attempt to break the command of the sea. To this end submarine vessels were built. They were not underwater vessels such as we know to-day, since they were surface-moving craft,

merely diving when they came within approach of the objective. But the Confederates placed implicit faith in these boats, which became colloquially known as " Davids " for the reason that they were designed to attack the " Goliaths " of the blockading fleet.

The most noteworthy result of this form of warfare in the above campaign was the sinking of the *Housatonic* of 1,264 tons and 13 guns on February 17, 1864. The outstanding features of the submarine which accomplished this feat were the planes or fins for movement in the vertical plane, otherwise rising and submerging, and the ballast tanks for assisting submergence. She resembled an ordinary ship in her longitudinal profile, was some 60 feet in length, and carried a crew of nine, of which number eight were delegated to the working of the screw. A torpedo of the spar type constituted the offensive armament. It was a bold and daring exploit, but as an example of what could be accomplished with the submarine it was negligible, inasmuch as the submarine, if such she may be called, together with the whole of her crew except the captain, was lost in the adventure.

Naturally, the successful sinking of the *Housatonic*, notwithstanding that it involved destruction of the underwater assassin, created a sensation. There were many who emphatically declared that the submarine would be the naval fighting machine of the future, and that it was wasted expenditure

to build further surface warships. The Federals appear to have been somewhat panic-stricken by the isolated success of the David in this instance, and concentrated efforts upon the acquisition of similar craft, but the conclusion of the fratricidal conflict intervened.

Although the vessels which figured in the American Civil War were described as being submarines they were not so; at least, not according to the modern interpretation of the term. They may be better described as primitive monitors, inasmuch as in the majority of cases they were designed in such a manner as to enable their armoured sides to be immersed, thus bringing the deck flush with the surface of the water. They could not be termed submarines for the simple reason that they possessed no diving capacities, or, if diving were possible, the period of submersion was strictly limited because no arrangements for carrying a reserve of respirable air were incorporated. The *Sputyen Devil* was a very interesting illustration of this practice, since she could be immersed to a depth of 9 feet, which brought her deck, on which the bridge was placed, level with the surface of the water. The torpedo, which constituted her offensive armament, was fired from the end of a submerged spar which projected from the bow of the vessel.

The termination of the American Civil War may also be said to have brought the second era of the submarine to a close. Invention in such a field

always receives a decided stimulus when war is raging, but once the conflict is ended there is an incidental slump in ideas. It was so in this case: the bottom fell from the market and the fountain of inventiveness concerning submarines dried up.

Many years elapsed before the subject occupied public attention once again. But in 1878, a British experimenter, the Rev. Garrett, turned his thoughts to the subject and evolved designs for a submarine, a boat in accordance with which was built in Liverpool. With this craft many tests were carried out, as well as with a larger vessel of similar design. While these trials achieved nothing of importance, they were noteworthy for one circumstance. A Swedish engineer, Mr. Thorsten Nordenfeldt, of some public importance, because of the gun which he had invented and which had come into universal use, was attracted to the Garrett submarine, and he embarked upon a similar line of research. A vessel was built, measuring 64 feet in length and displacing 60 tons. The little boat was driven both above and under the water by steam engines.

The appearance of Mr. Nordenfeldt upon the scene of investigation may be regarded as representing the turning-point in the history of the submarine. Hitherto, such inventors as had ventured to attack the problem had, in common with the average member of that community, been rich in ideas but poor in pocket. Extreme economy

had to be observed in constructional work owing to limited funds, the outcome invariably being an imperfect vessel. But in this instance there were no restrictions. Mr. Nordenfeldt was an engineer and had his substantial private resources upon which to draw, thus ensuring that the best work would be accomplished irrespective of expense, while at the same time possessing all the facilities available for transforming abstract theories into the concrete. Accordingly, the first Nordenfeldt submarine was a well-designed and well-built vessel. It was avowedly founded upon the Garrett model, but with this difference—all the defects in the latter craft were eliminated, only the most satisfactory features, associated with certain ideas which Mr. Nordenfeldt evolved, being incorporated.

The trials with this vessel were so promising that a second and larger vessel was built. This boat measured 100 feet in length, displaced 160 tons, attained a speed of 12 knots upon the surface, and was capable of being submerged to a depth of 50 feet. Here, again, steam engines were utilised for propulsion both on the surface and below the water. The armament comprised two torpedoes together with two Nordenfeldt 25-millimetre quick-firing guns. Movement in the vertical plane was carried out by means of vertical propellers, while bow planes served to preserve the horizontal position of the craft.

The experiments with the two Nordenfeldt vessels occasioned considerable and worldwide interest.

So much so that the original vessel was purchased by the Greek Government, which action prompted the latter's traditional enemy, the Turk, to go one better and to purchase two similar craft.

Notwithstanding this auspicious beginning, the Nordenfeldt submarines were a dismal failure when subjected to underwater work. The vital elements concerning the principles of submarine construction had not been mastered. When the Turkish submarines were being tested in the Bosphorous they displayed an unconquerable desire to make acquaintance with the sea-bed. Mr. Garrett was in command of the vessel, but he found his charge extremely tender, evincing a strong desire to move like a see-saw directly the attempt at submergence was made. In fact, disaster almost accompanied the trials, the water gaining an entrance before the lid of the conning tower was closed properly. Nevertheless the Turkish Government purchased the craft, but they never succeeded in coaxing or forcing a crew to man her, with the result that she was thrown upon one side at Constantinople and left to rust.

The attempted perfection of the submarine in those days suffered from the selfsame disability as the attempted perfection of the airship and aeroplane of that period. The steam engine was the only reliable prime mover in existence. What was required in the case of the submarine, as urgently as in connection with its consort of the air, was a light powerful engine using gas as fuel for surface

propulsion and a light, compact, non-oxygen-consuming, odourless and flexible drive for the vessel when submerged. The latter problem was first solved by the perfection of the electric motor and the secondary battery or accumulators. Subsequently, the first-named issue was equally overcome by the invention of the light internal combustion engine using petrol or gasolene vapour as fuel. The appearance of the latter prime mover effectively solved two great problems in the field of mechanical propulsion simultaneously—human flight and movement under water.

The potentialities of electric propulsion were demonstrated conclusively in the first modern French submarine, the *Gymnote*. This vessel was the product of a French engineering genius, Depuy de Lôme. In fact, this engineer may be said to have paved the way for further study in two realms —the air and under water respectively, since he contrived the first practicable dirigible airship, which was named after him. Unfortunately, the completion of his designs for the submarine were interrupted by his death. For many years they lay dormant and practically forgotten, but later they were brought to light by an intimate friend, Gustave Zédé. With the march of progress it was necessary to revise the original designs of Dupuy de Lôme, so as to bring them into line with contemporary thought and practice. This was done successfully by M. Zédé. The *Gymnote* re-

sembled a cigar in shape, measured 59 feet in length by nearly 6 feet beam, and displaced 60 tons. In this vessel electricity was employed for both surface and underwater propulsion, the motor, developing 55 horse-power, being supplied from a secondary battery of 564 cells. While the electric machinery was somewhat intricate, it commanded attention for its comparatively light weight and efficiency. The installation weighed 4,400 pounds and the radius of action at the maximum travelling speed of 6 knots was 35 nautical miles upon a single battery charge. At two-thirds speed the radius was about 100 miles. Subsequently, the mechanical installation was superseded by a lighter equipment.

The *Gymnote* was essentially an experimental vessel, but she proved very successful. It impressed the French Admiralty so effectively that they decided forthwith to introduce the submarine into the French Navy. A larger vessel was designed by the Naval Constructor and, as a compliment to the builder of the *Gymnote*, was named after him. The *Gustave Zédé*, which was 160 feet in length and had a beam of 12½ feet, displaced nearly 270 tons. She was driven by electric motors developing 720 horse-power and carried three 17½-inch Whitehead torpedoes as her offensive armament. The *Gustave Zédé* proved a complete success, and this result was the cause of an unprecedented outburst of national enthusiasm, culminating in the opening of a public subscription by *Le Matin* for defraying the cost of

further boats of this type. The movement appealed to the French nation, which subscribed the sum of £1200—$6000—towards the construction of two further craft. Such was the beginning of the French submarine navy, which to-day is of impressive proportions and strength.

At the same time, the problem of submarine navigation had attracted the attention of two diligent inventors in the United States. The one was Mr. Simon Lake, the other Mr. John P. Holland. Each pursued an individual line of experiment, and each elaborated a distinctive design. These two types, however, have become recognised as models for underwater craft among the Powers, and have constituted the foundations upon which other designs have been built. The Holland was adopted by Great Britain, while the United States Government has used both. For this reason the Lake and the Holland submarines may be considered to be the standard types of to-day, at least outside Germany, France and Italy, which countries have fathered local effort and endeavour in this peculiar field of invention. But even in these instances the influence of the American inventors is very pronounced.

CHAPTER III

THE LAKE SUBMARINE

All early efforts towards perfecting the submarine were made with one end in view: the destruction of hostile vessels. In other words, it was regarded simply as a naval unit. It did not occur to the pioneers that the underwater vessel might be devoted to the exigencies of peace and commerce. Yet this was the guiding principle of Mr. Simon Lake when he embarked upon the project of submarine navigation. This inventor was impressed with the immense number of wrecked vessels distributed upon the sea-bed around the coasts, not only of his homeland, but of other countries of the world. These wrecks represent a fabulous sum of money, and as a large proportion of the cargoes which are still imprisoned in their holds is of an imperishable nature and of distinct value, he conceived the idea of salvaging this incalculable wealth by means of the submarine.

To this end he built his first submarine, *Argonaut Junior*, in 1894. She was certainly a primitive craft, wrought in wood, and measuring 14 feet in length by 4½ feet beam and 5 feet deep. She differed in every particular from any submarine

previously described, since she was not designed to move through the water in the manner generally understood, but to travel along the sea-bed, for which purpose she was fitted with four wheels, the larger pair of which was driven by means of a crank. Another feature was a small compartment in the bow of the vessel from which it was possible for a diver to step out on to the sea-bed and so facilitate the gathering of articles or entrance to a sunken wreck. This boat was also fitted with a compressed air supply contained within a soda-water tank. The boat was designed to submerge to a maximum depth of 20 feet. Although crudely contrived and built by the inventor himself, it served to demonstrate his ideas, and the success of the experiments therewith brought in sufficient capital to permit the construction of a larger craft.

The second vessel, christened *Argonaut*, was a more pretentious piece of work. She measured 36 feet in length by 9 feet beam, and was fitted with a 30 horse-power explosion motor together with a dynamo, air-compressor, searchlights and other equipment. The outstanding features of the original craft were retained and developed, notably the wheels for moving over the sea-bed and the diving compartment forward. This vessel conclusively demonstrated the possibility of fulfilling the inventor's claims, and during the year 1898 her crew of five men covered no fewer than

2000 miles, travelling, both awash and submerged, up and down the Atlantic seaboard.

Hitherto it had been maintained that a submarine's activities would be restricted to conditions of calm weather, but this inventor proved this contention false, for he put out to sea in his little vessel during October and November and weathered furious gales without suffering the slightest ill-effects. The claims of submarines to seaworthiness were thus strikingly established, especially as, during the same period, over 200 ordinary vessels were wrecked upon the Atlantic coastline of North America.

This vessel was returned to dock for enlargement and for the incorporation of certain improvements. These modifications concerned the addition of greater buoyancy to the vessel while awash, together with enlarged deck space and increased fuel-carrying capacity. The alterations brought the length of the vessel to 66 feet over the superstructure, and 56 feet over the circular portion of the hull, which had to resist the pressure of the water, with a maximum beam of 10 feet. The original driving machinery was replaced by a more powerful installation, comprising a 60 horse-power petrol or gasolene motor for propelling the vessel while upon the surface and also along the sea-bed, together with a dynamo, air-compressor, ballast pumps and so on.

This submarine carried a sufficient air supply to enable her to remain submerged for a continuous

period of forty-eight hours, but as in salvaging operations such a period of submergence would not be adequate, the inventor incorporated an ingenious means of enabling her to remain under water for an indefinite period. From the forward part of the vessel a vertical pipe, resembling a hollow mast, extended to a point above the surface of the water. At the stern, extending from the engine-room, was another similar pipe also running upwards into the open air. In this manner a perfect air circulation through the vessel was obtained, inasmuch as the vitiated atmosphere and exhaust from the engines passed up the astern pipe, while fresh air descended the forward pipe. The enlarging operations also rendered possible the introduction of adequate sleeping quarters for her crew, so that when engaged upon salvaging operations, the vessel could remain upon the sea-bed until the task was completed, or until it became necessary to rise to the surface to change crews or to restock the fuel tanks and the commissariat.

Many interesting experiments were carried out with this vessel, which certainly served to substantiate the claims that a submarine might profitably be employed in wreck-raising and salvage work. The inventor also maintained that it would prove of value in the coral, pearl and sponge fisheries; in the performance of subaqueous engineering operations, such as the laying of foundations for piers, docks, lighthouses; the removal

of rocks and other debris in a fairway; as well as proving of pure scientific interest in the investigation of the sea-bed and marine life.

The commercial applications of the submarine as outlined by the inventor were certainly attractive, and, as experiment revealed, quite practical, but the idea never appears to have been adopted seriously in the field for which it was expressly designed. This indifferent attitude towards the invention caused Mr. Simon Lake to turn his attention to the utilisation of the submarine in another direction and one with which the underwater boat had always been identified, namely, destruction. Accordingly, in 1901 the inventor commenced the construction of his first naval submarine, the *Protector*.

But in the naval type of Lake submarine the outstanding features of the wrecking underwater craft are preserved, namely the wheels for travelling upon the sea-bed and the forward compartment whereby divers can leave and enter the boat whenever the occasion arises. So far as the wheels are concerned these are mounted upon what may be described as swinging axles. In order to permit the wheels to be "stowed" when desired, small recesses are provided in the hull for this purpose. The extension and withdrawal of the wheels is a simple matter. When the wheels are stowed the symmetrical contour of the hull is preserved and there is reduced resistance to the water.

The diving compartment is probably the most

interesting feature. It is entered by means of an air-lock similar to those utilised in connection with the Greathead shield in tunnel-boring operations. The diving compartment is provided with a kind of hinged trap-door in the hull. When it is desired to explore the sea-bed the boat is brought to rest and anchored. The diver or divers don the diving gear and enter the air-lock. From this they pass into the diving compartment. The trap-door is released from within the hull, with which it fits flush and in a watertight manner, and is dropped down, forming a kind of ramp or inclined way to facilitate the diver passing in and out of the submarine. The atmosphere within the diving compartment is maintained at pressure, this pressure being adequate to counterbalance the outside pressure of the water so that the latter cannot enter the compartment. The situation is precisely similar to that existing at the working face of a tunnel-boring shield which is being driven through soft water-laden sand or mud. The pressure of the air holds back the slipping soil so that it cannot overwhelm the excavators.

The Lake submarine differs in its general outline from the prevailing type of underwater boat. Whereas the latter are cigar or spindle shaped, the former, in its longitudinal profile, recalls that of the ordinary vessel. The water-resisting section of the hull is circular, as this is the form best adapted to resisting the pressure of the water, but it is

crowned by a superstructure resembling that of a ship, or, to be more correct, that of a torpedo-boat, the object being to give increased deck space and greater longitudinal stiffness to the craft. When the vessel is travelling in the "light" condition she resembles a torpedo-boat lying very low down in the water, or perhaps, to be more precise, she has the appearance of a monitor.

The perfection of this design has divided the science of submarine construction into two camps. There is the one which advocates the Lake type with its deck superstructure, and the other which adheres to the spindle form purely and simply without a superstructure, or, if such be incorporated, of so very insignificant a nature as to be negligible. Thus the Lake type, which is favoured by the French with the Laubeuf submarine, the Germans with the Germania and Italy with the Laurenti models, constitutes the one camp; while the other is supported by the Holland, which is the prevailing type in the British Navy and which is partly adopted by the United States, Russia, Holland, Japan and so on.

In the Lake type the superstructure is carried throughout the entire length of the vessel. In the rival type the superstructure is varied, but in all instances it terminates considerably short of the two extremities of the boat. The main advantage of the superstructure, as advanced by its adherents, is that it renders the vessel more seaworthy and

steadier when travelling awash or in the light condition in a heavy sea. The opponents of this system maintain, on the other hand, that while it may ensure greater longitudinal stability, it retards travelling speed, or, expressed in other words, to attain a given speed with vessels of identical displacement and dimensions, more engine power is required for the former than for the latter.

It is also averred that the Lake type of underwater craft is not a true submarine. The popular impression is that any vessel which travels beneath the surface of the water is a submarine, but strictly speaking this is not so. Underwater craft are divided into two broad classes, "submarine" and "submersible." Both terms emanate from France, where they were employed to differentiate between two types of boat. The "submersible" was accepted as indicating the type which was able to travel upon the surface of the water in the manner of an ordinary ship, and was driven by engines which were in open communication with the atmosphere; but when the occasion arose, they could be submerged by closing the outlets to the atmosphere, descending beneath the surface, and running underwater under another system of propulsion, such as electricity. Hence the term "submersible."

On the other hand, the "submarine" was taken to represent the vessel which was designed essentially for underwater travelling, being fitted with a system of propulsion therefor such as

electric motors. When such craft were travelling awash they had to depend upon the same source of power, being deficient in independent engines for moving under such conditions. They also had to be attached to a base to enable the secondary batteries to be recharged, while, when travelling awash, the freeboard was extremely low. This, however, was immaterial, inasmuch as they could move along the surface in the sealed condition just as if they were under the water. It was not necessary to open up to derive supplies of air for the operation of the surface-driving machinery, as is the case with the submersible, which uses steam engines or explosion high-speed motors. But the term has no significance to-day outside technical circles. The word submarine is a generic term for any vessel which is able to move *sousmarin*, i. e. "under the water."

The reasons why the Lake is not considered by its critics to be a true submarine, but only a "submersible," are many, but they are merely of technical import. Generally speaking, however, the "submersible" is now considered to indicate any vessel which has the decided superstructure and the general ship profile and which sinks upon the even keel, this being the outstanding claim of the Lake class. The vessels belonging to the second distinctive class are true diving boats, inasmuch as they are declined to descend and inclined to ascend. The case of the airship and the aero-

plane may be cited as an analogy. As the airship can ascend vertically or on an even keel by the discharge of ballast, and can descend in a similar manner by letting out the gas, so can the Lake type descend in the vertical plane or upon the even keel by admitting water into the ballast tanks, and reascend by expelling the water from these tanks. In the case of the aeroplane the machine is given an inclination for ascent and a declination for descent, so that it ascends and descends diagonally. The spindle form or cigar-shaped submarines descend and ascend in a similar manner, although the two movements are assisted by means of filling or discharging the ballast tanks. The supporters of the Lake design maintain that it is impossible for vessels of this type to make a headlong dive, which they regard as a decided drawback to the opposite class. This has been a point of considerable and animated discussion in technical circles, but it is merely of academic interest, inasmuch as the various Powers, when they have lost a submarine and have succeeded in retrieving the wreck, or divining the cause of the disaster—of course collision is eliminated from the issue as such is common to both types—have never communicated the results of their investigations to the outside world.

The *Protector*, although built in the United States and at the expense of the company operating the Lake patents, was not purchased by the American

Government, but was sold to Russia and proceeded to Vladivostok. She was then renamed, and is now known as the *Ossetyr*. On the official trials she attained a maximum surface speed of 9·3 knots under the combined effort of her gasolene and electric motors. With the former alone and in the light cruising condition she notched 8·5 knots. With conning tower awash and under similar propulsion she made 7·4 knots, while totally submerged and driven only by the electric motors she recorded a speed of 5·4 knots. This initial purchase was supplemented by the acquisition of additional craft of this type, some of which are delegated to duty in the Baltic Sea.

It is claimed for the Lake submarine that the ship form of superstructure and deck contribute to greater steadiness and seaworthiness when the vessel is running light. The space in the superstructure is utilised for the stowage of deck hamper, fuel tanks, lubricating oil tanks, compressed air reservoirs and so forth. The great advantage of this disposition, it is averred, is the release of greater space within the submarine proper for the comfort and convenience of the crew.

During the past two or three years many improvements have been introduced to which reference is made elsewhere. While the Lake submersible has not such an extensive vogue outside the United States of America as the diving class, it has proved highly successful in the land of its origin.

CHAPTER IV

THE HOLLAND SUBMARINE

WHILE Simon Lake was prosecuting his experiments with a submersible vessel capable of facilitating subaqueous engineering which could be employed in salvage operations, another American inventor was attacking the same problem, but with a different purpose and in a distinctly dissimilar manner. This was Mr. John P. Holland.

This inventor from the first realised that the ultimate utility of the submarine was as an underwater fighting unit, and he concentrated his energies towards the perfection of a craft for such work. He adopted the cigar-shaped type of hull, or, as it is technically termed, the spindle form. The first ship, named after its designer and to-day the generic name for vessels of this type, was completed in 1898. It was a small boat displacing about 70 tons when submerged, and in the latter condition had a speed of 5 knots, another knot being notched when the craft was travelling awash.

The Holland submarine created a sensation when it was recognised throughout the world that a practical submarine had at last been evolved. She ushered in what may be described as the modern

line of thought in connection with submarine naval design and science. She was subjected repeatedly to searching and comprehensive tests, not only by the American Government, but by the representatives of various other powers whose attention to the possibilities of underwater fighting ships was aroused by the performances of the Baby Holland.

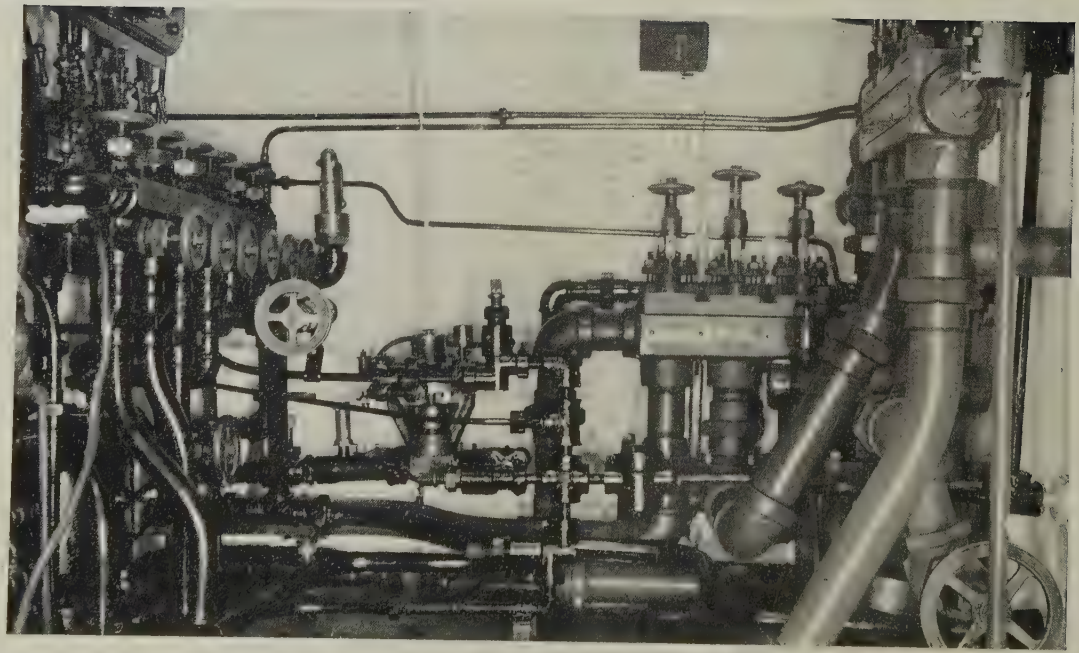
The upshot of these trials and investigations was startling, and affected the whole world in a very appreciable manner. The British Admiralty, which, hitherto, had apparently regarded submarine fighting with indifference, manifested an unexpected and active concern in the subject. So much so that Messrs. Vickers, Limited, in conjunction with, or rather at the instigation of, the British Government, approached the inventor and finally acquired the master patents and exclusive rights for manufacture in Great Britain. The arrangement was distinctly complete: the idea was purchased lock, stock and barrel, the inventor having no further interest so far as Great Britain was concerned.

The Admiralty and Messrs. Vickers, Limited, completed this arrangement for one specific reason: the Holland had triumphed. It was far from perfect, as may be imagined, since every new invention is capable of considerable development in accordance with the accumulation of experience and the advance of progress. But this little Holland was a nucleus—the ultimate outcome of

[*Cribb*

BRITAIN'S FIRST SUBMARINE

One of the five "Baby Hollands," built in 1901–3. They were sister-ships of the *Adder* class of the United States, and displaced 122 tons submerged. These little vessels constituted the foundation of Britain's present mighty underwater Navy.



THE MECHANISM OF THE MODERN SUBMARINE
Control station for the air and auxiliary pumps.

which it was impossible to foresee at that time. But it is upon the Holland that the present imposing British submarine fleet has been built.

One outcome of this enterprising move was the establishment of a monopoly in submarine boat-building in Great Britain. From the day when the designs were acquired the evolution of the Holland submarine, so far as Great Britain is concerned, has been wrapped in an impenetrable veil of secrecy. It has been stated that the American and British Holland submarines of to-day are virtually identical, but this is purely a surmise, and, be it remarked, a somewhat hazardous conclusion, because no one outside official and manufacturing circles has any knowledge of what developments the British engineers have carried out. The question is rendered additionally obscure from the fact that in this phase of naval engineering and construction Great Britain did not pose as a producer for the markets of the world. The vessels have been built for the British Navy. The only exception to this rigid rule was the manufacture of one or two vessels of this type for the navy of Britain's Eastern Ally, Japan.

So completely has the curtain of secrecy been drawn over naval operations in the British Isles that nothing is known concerning the essential details of the British submarines. The particulars vouchsafed to the public from time to time have been far from illuminating, while, since the outbreak

of war, these glimpses of what Britain is doing have been completely suppressed.

In the United States, however, less secrecy has been maintained, since the Electric Boat Company, which is the organisation carrying out the manufacture of these vessels, in addition to building for the American Government supplies any market which may desire to acquire such craft. This company has pursued its own line of development and improvement, and has built submarines for nearly every Power, including Japan, Russia, Austria and Holland. The American Government was so impressed with the Baby Holland that it was purchased in 1900 and commissioned in the United States Navy. Some idea of her serviceability may be gathered from the fact that she continued in active service for ten years, not being struck off the active list until 1910, when, owing to the rapid strides which had been made, she was hopelessly obsolete. But instead of meeting an undignified end upon the scrap heap, the first Holland was given a resting-place of considerable honour. She was taken to the Naval Academy at Annapolis, where she is preserved as a naval relic—the first submarine to be officially employed in the United States Navy.

The American Government emphasised its opinion of the Holland system by ordering, at the time of purchasing Mr. Holland's first sea-going boat, seven larger craft of 122 tons displacement

when submerged. These vessels were fitted with 160 horse-power petrol or gasolene engines for surface propulsion and 70 horse-power electric motors for submerged movement, driving a single propeller, the speed upon the surface being 8½ knots and 7 knots submerged. These vessels carried a single torpedo tube and two additional torpedoes. The offensive armament was somewhat limited, but, in the early days, the submarine was regarded in the manner of a home defence unit, attached to some base in close proximity, the result being that the craft could return speedily to secure a further supply of ammunition. The radius of action of the above vessels, which were known as the *Adder* class, was 300 miles when travelling awash at full speed, and 49 miles at 5 knots, or 25 miles at 7 knots, when running submerged.

As with their prototype, these seven vessels had a long spell of useful service, and, in 1911, they established their seaworthiness in a convincing manner when four of the flotilla proceeded to the Philippines under their own power, escorted by a parent ship, and successfully completed the long sea voyage across the Pacific without a single hitch. It is not surprising, in view of the foregoing successes, that the American Government ventured still farther with this class of submarine by calling for three new vessels displacing 170 tons submerged, with a surface speed of 9 knots and a submerged speed of 8 knots respectively. This was the *Viper*

class, followed almost immediately, or rather accompanied contemporaneously, by the *Octopus* class.

This last-named vessel became remarkable from many circumstances. She was the first submarine to be fitted with twin screws. She has a submerged displacement of 273 tons, a surface speed of 11 knots developed by an explosion motor of 500 horse-power, and 10 knots submerged from an electric installation developing 320 horse-power. The *Octopus* was regarded essentially as an experimental vessel, inasmuch as she was submitted to tests which previously never had been attempted. One of the most sensational was the submergence test described in another chapter, while others, no less startling, were made in order to determine the sea-going capacities of the submarine in addition to the definite determination of many other points which heretofore had not been settled. These latter problems, however, were essentially of a technical character.

In reality the *Octopus* indicated a demarcation and an important step in the history of submarines. Hitherto they had been regarded purely and simply in the light of harbour and coast defence craft, but the new vessel was designed to establish whether the underwater boat might not be regarded profitably as a reliable sea-going unit. At the same time, the *Octopus* was ranged against competitors, the design and manufacture of submarines in America having reached a stage where it became a

question of the survival of the fittest. Up to this time the development of the submarine had been effected upon lines which were far from being coherent. The respective designers of the distinctive types had advanced claims for their individual expressions of submarine handiwork, and the moment was accepted by the Government as being propitious for deciding some very complex questions. However, the Holland design vindicated all the claims advanced by its sponsors, and to such effect that another forward movement was made by the Government, which called for seven additional craft of this class, four of which were to be virtually larger and improved units of the *Octopus*, displacing 337 tons when submerged, and with speeds of 13 and 10½ to 12 knots when travelling upon the surface and submerged respectively.

These vessels carried out many remarkable performances, the most noteworthy being the sea-going journey of 150 miles from Newport, Gloucester, the greater distance of which was covered by the boats travelling submerged. Indeed, it is probable that the little craft would have journeyed from point to point entirely underwater but for the fact that the course extended across the shoals of Nantucket, where insufficient depth of water compelled their return to the surface to negotiate the dangerous stretch. The fact that the whole of the seven vessels successfully accomplished this difficult journey without the slightest mishap, and

without submitting a single or the slightest hardship upon the crews, was regarded as remarkable.

This run proved an eye-opener, not only to the United States, but to the world at large in another sense. It proved most emphatically the cruising possibilities of the submarine. Nearly the whole of the boats remained submerged for eleven to twelve hours, only coming to the surface at night, as necessity compelled, to enable the accumulators or storage battery to be recharged by means of the gasolene engines, the radius of action upon the electric battery charge being 100 miles at a speed of 5 knots. One vessel made a run for some time at a depth of 60 feet. Two days and nights were occupied in the test, and the excellent condition of the crews upon return to port occasioned considerable comment. For the first time it was realised that a submarine could proceed upon a certain mission and could remain away for some days on end, provided she were supplied with adequate fuel. The fact that the vessel could run submerged for twelve hours on end—virtually a whole day—coming to the surface at night to recharge her batteries and to complete any desired duty under cover of darkness, revealed a new vista of applications and possibilities of the underwater craft, which, by the way, have been substantiated very clearly during the war.

The Holland belongs to what is known as the diving-boat class as distinct from that which sub-

nerges upon an even keel. That is to say, the vessel s set to an angle of declination when descending nd to an angle of inclination for the purposes of scent. The angle, however, is very slight, so that ne boat follows what might be described as a long asily sloping bank in the respective movements. Vhile the angle may be as great as 4 or 5 or more egrees to meet sudden emergencies, the angle nder normal conditions varies from 2 to $2\frac{1}{2}$ egrees.

The Holland submarine carries very little top amper such as a ship-shape deck. The super-tructure is virtually non-existent, comprising nerely a certain stretch of level deck for the con-enience of the crew, but this deck terminates far nort of the extreme bow and stern respectively. his form of superstructure, as experience has roved, is quite adequate to ensure steadiness and eaworthiness when running awash, but its maximum alue is revealed when the boat is submerged. In ne submersible the ship-shape superstructure acts s a drag upon the vessel owing to the resistance hich it offers to the water. On the other hand, y the observance to the spindle form which is char-cteristic of the Holland boats, the submerged speed, isplacement for displacement, and engine power r engine power, is higher in the Holland than in s competitors equipped with a superstructure.

The development of the Holland submarine is ery graphically illustrated in connection with the

development of the United States Navy. Whereas the first Holland of the American Navy measured 54 feet in length by $10\frac{3}{4}$ feet beam, the latest vessel is 265 feet long by 23 feet beam. The first naval craft of this type was fitted with a 50 horse-power petrol or gasolene motor giving a surface speed of 6 knots: the modern craft carries engines of sufficient power to impart a surface speed of 1 knots. Whereas the electric motors of the first craft for submerged travelling developed 50 horse-power, giving a speed of 5 knots per hour, the present electric installation develops considerably more than 1000 horse-power, which ensures a submerged speed of 11 knots.

CHAPTER V

THE MECHANISM OF THE SUBMARINE

Upon those rare occasions when members of the eneral public are permitted to visit and to inspect battleship, and thereby are enabled to obtain a irect impression of the measures which are being aken to ensure the national security, intense interest nd unqualified admiration are manifested. The vonders of the warship are so many and so varied. But of the submarine comparatively nothing is nown. None but a privileged minority, and those vho have business with these craft, are favoured vith the opportunity to go below to roam the vessel, nd to marvel at the wondrous and ingenious levices which are housed in a shell of steel some oo feet or more in length by 24 feet in diameter.

Perhaps this is as it should be : possibly for once he authorities are correct in their attitude of with-olding from general knowledge the secrets of " the courge of the seas." It must be confessed that he submarine is not an ideal vessel for public in-pection. Its capacity is so severely limited that personally conducted tour is almost impossible; or within a small compass is packed an apparently opeless mass of intricate machinery. When, how-

ever, one recalls the keen and bitterly contested race among the nations for submarine supremacy, it is obvious that the outstanding features of a certain underwater vessel must be screened from publicity.

Although personal visits to craft of this character are denied, it is possible to give a general idea of the mechanical equipment of the modern submarine. It has been dismissed by the sailorman as a " box of tricks." The description is apt. To mention that its operation depends upon a round two hundred distinctive features, each of which fulfils a definite function, is to tell nothing of the bewildering array of mechanism which is stowed within the fish-shaped body of steel. It conveys no idea of the marvellous construction, nor of the character of the numerous and elaborate contrivances which are essential to the smooth, regular and safe working of this machinery.

The shell, or hull, either follows the broad lines of the fish, or the general above-water aspect of a torpedo-boat, according to whether the vessel is of the spindle-shaped diving or the submersible class of submarine. In the case of the British and American Holland the fish shape is adopted, the resemblance being accentuated somewhat by the light self-baling superstructure which recalls the dorsal fin. Apart from this distinctive general appearance, the construction of the submarine up to a certain point follows the lines of the surface

vessel. There are what might be described as the double bottom, especially amidships, containing the ballast tanks whereby the submergence of the vessel is controlled, as well as additional cells or compartments, suitably disposed, known as trimming tanks, which, as their name implies, are for the purpose of maintaining the requisite trim of the vessel. Other cellular compartments are used for the storage of the fuel oil and so on.

As is well known, a submarine is induced to submerge by the deliberate destruction of its capacity to float. This is accomplished by admitting water into the various tanks to the requisite degree, the admission being controlled through valves. Then, when it is desired to return to the cruising condition, the water is expelled from these tanks and replaced by air, which restores the floating capacity. But when a submarine is submerged it always preserves a certain degree of buoyancy. This is essential, because, if the weight of the vessel exceeded her displacement, she would sink to the bottom in accordance with the laws of Nature. Even when the commander of the submarine seeks the sanctuary of the sea-bed, and lies there to escape his enemy, his vessel still retains what is termed reserve buoyancy, so as to enable him to move when the opportune moment arrives. It is only when this reserve buoyancy is utterly destroyed that the vessel may be considered to have foundered.

The manipulation of the water ballast, as it is

called, is controlled by means of pumps, and these must be of sufficient power to overcome the pressure of the surrounding water when the submarine is moving at the maximum designed depth. We will suppose, for instance, that the vessel has descended 250 feet and desires to return to the surface immediately. Now at this depth the surrounding water pressure is no less than $108\frac{3}{4}$ pounds per square foot: in other words, this is the extent of the back pressure which the pumps must overcome before the water can be expelled from the tanks. It will be seen, therefore, that the pumps must be extremely powerful if they are to perform their allotted function speedily. They are driven by electricity, which is the only energy available when the boat is submerged.

The most conspicuous feature of the cruising submarine is the small structure rising from her narrow slender deck. This is the conning tower, which may be described as the brain of the underwater vessel, since it is from this position that every movement of the vessel is controlled. The roof of the conning tower serves as a navigating bridge when the vessel is travelling upon the surface, being fitted with compass, steering wheel and other instruments usually found upon the bridge of a ship, all of which, together with the stanchions and the "dodger," can be removed to the interior of the vessel when it is proposed to submerge. The deck itself is somewhat narrow and, except in those

vessels which sink upon an even keel, extends for only about one-third of the total length of the craft.

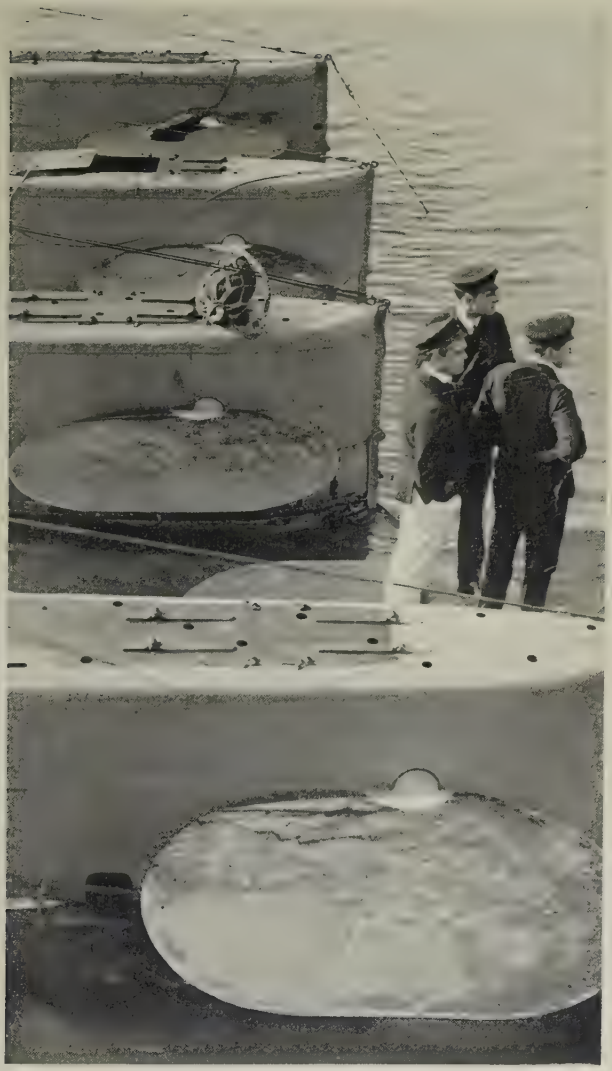
Access to the interior of the conning tower is obtained through a small hatchway fitted with a domed cover, which is hinged like a lid, and is closed from within by means of a dog so as to form a perfect watertight joint. The compartment is somewhat cramped, even in the largest submarines, especially in regard to head-room. In this compartment are the eye-pieces of the periscope—the " eye " of the submarine—together with a compass and a number of recording instruments, tell-tales, and telegraphs for communicating with different parts of the vessel. The conning tower is also provided with a number of ports through which the navigator may scan and reconnoitre the surrounding waters when travelling in the awash condition with the conning tower closed. Here, also, are certain emergency levers for performing some definite duty instantly at a critical moment, such as the blowing-out of the ballast tanks.

In reality the conning tower is the only part of the submarine which is placed outside the hull proper. The floor of this compartment constitutes the shell of the vessel, the latter being entered through a second hatchway. It is possible to shut off the conning tower from the remainder of the ship, if desired, by means of a special hatch or cover. This arrangement contributes to the general safety, in the event of the conning tower being damaged

or shot away by gun-fire. By closing this second hatch the interior of the submarine is rendered absolutely watertight, and she can submerge in safety.

Immediately below the conning tower is the operating or navigating compartment, placed upon the main and only deck within the submarine. Here are the various devices for navigating the vessel, steering wheels for moving the ordinary rudder, as well as for the manipulation of the hydroplanes or horizontal rudders. The navigator is surrounded by recording instruments, tell-tales, compass and other necessary indicators, duplicates of those in the conning tower, to assist him in controlling the vessel. Immediately facing him is a pressure gauge, the moving finger of which shows the angle at which the vessel is travelling in descending or ascending, as the case may be, while another indicator shows whether the craft is maintaining an even keel when running submerged.

Right forward are the torpedo tubes, disposed in a nest. In the latest submarines there is a similar array at the rear of the vessel for astern firing, while in some vessels pairs of tubes are mounted upon the fore and aft sides of the conning tower respectively. When there are two or three tubes to a nest they are generally disposed one above the other in a vertical row, but in those instances where four tubes are fitted the favoured arrangement is two pairs side by side. The tubes may be



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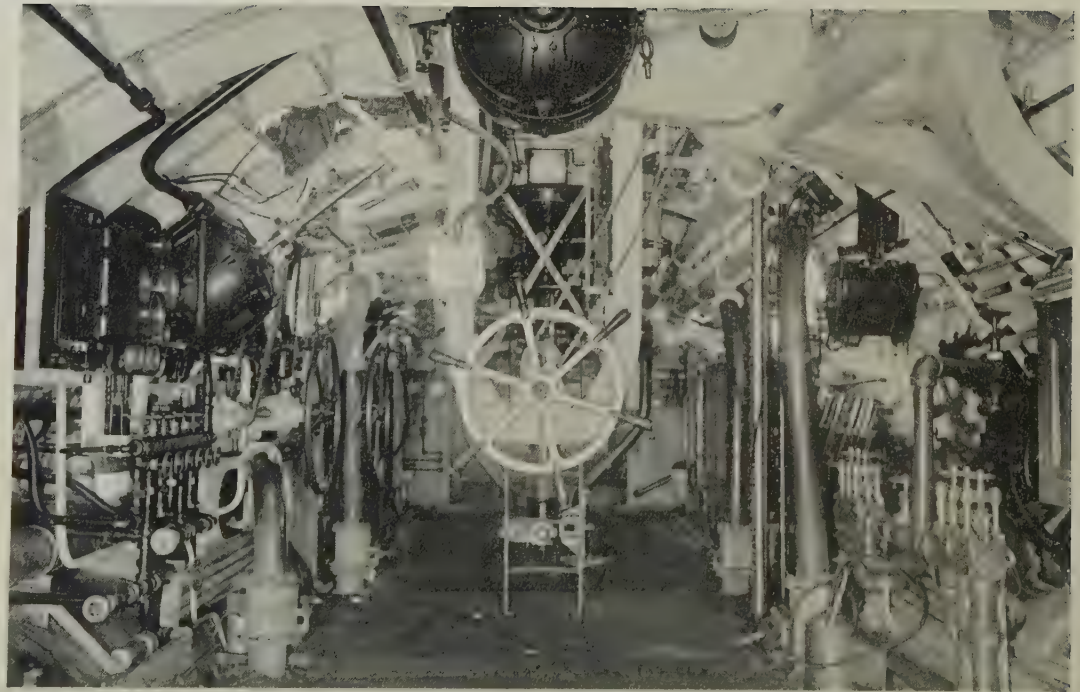
FORWARD HYDROPLANES OF BRITISH SUBMARINES

These horizontal rudders serve for steering in the vertical plane when the boat is travelling submerged, as well as controlling the angle of descent and ascent.



and invariably are, kept charged ready for instant service, being loaded before leaving port. The reserve supply is carried in the magazines, which are located near the tubes to facilitate and expedite loading.

The breech blocks are operated by means of handwheels, which, when given a slight turn, enable the block to be swung sideways, clear of the bore, to permit the loading of the tube. The reserve torpedoes are carried upon cradles and are swung into the tubes and pushed home. The breech block is closed and rendered airtight by a slight reverse turn of the handwheel. The outer end of the tube is sealed with a cap to prevent the incursion of water. This is moved to leave the mouth of the tube open immediately before firing the torpedo, and is closed again when the missile has sped on its way, this opening and closing action being performed from within the submarine by suitable gear operated by an electric motor. The torpedo is fired by compressed air, a tank or reservoir being kept charged to the prescribed pressure. A valve controls the passage of the compressed air from the reservoir to the tube, and is operated by a small wheel.

Abaft the navigating room is the machinery section, which contains not only the engines for driving the submarine upon the surface and under water respectively, but all the auxiliary machinery, such as the pumps for maintaining the compressed

air supplies and for emptying the ballast tanks, lubricators, fuel supply, ventilation, and so on.

The internal combustion engines are disposed in two batteries upon either side of a central gangway, since the modern submarine is driven by two or three screws. The exhaust gases pass from the cylinders through a muffler which is generally placed in the superstructure overhead and outside the vessel. The muffler fulfils a function similar to that of the silencer of the automobile, the gases finally escaping into the open air, the internal combustion engines, of course, only being in use when the vessel is travelling awash. When moving on the surface the opening of the conning-tower hatch for the supply and free circulation of fresh air is obviated by a system of ventilation. The mouths of the ventilators are level with the floor of the outer deck of the conning tower and are also fitted with watertight hatches which are closed preparatory to submergence. The ventilation within the vessel is of the forced type, fans being driven by electric motors. In this manner it is possible to keep the interior atmosphere perfectly clear, sweet and cool, even when the explosion motors are running.

The propeller shafts are coupled to the engines by means of large clutches. If high-speed gasolene engines are used, the employment of reducing gear is essential, so as to bring the engine speed down to that required for the propellers; but in the latest types of submarine, especially in Europe, this highly

volatile and inflammable fuel is no longer employed, as described in the succeeding chapter.

The internal combustion engines are also connected through a clutch with the electric motors. While the electric current is drawn from secondary batteries or accumulators when the vessel is travelling underwater, advantage is taken at such time as the submarine rises to the surface, to couple up the oil engines with the motors in order to recharge the accumulators. In this way, it is rendered possible for a submarine to remain away from port for a prolonged period. The accumulators are only of sufficient capacity to supply energy for driving the vessel for about 100 miles at full speed, which represents about 8 hours' continuous travelling. By coupling the explosion engines to the electric motors, however, thereby converting the latter into generators, upon every favourable opportunity when coming to the surface, it is possible to keep the accumulators charged to their full capacity so that the underwater efficiency of the vessel may be maintained.

The space beneath the deck is utilised for a variety of purposes and is subdivided in a somewhat intricate manner. For instance, the electric accumulators are carried under the floor, the cells and integral parts being of such convenient size as to permit easy passage through the hatchways of the vessel when overhauling and renewals become necessary. The dimensions, as well as the weights

of individual parts within the submarine, must be carefully considered in order to facilitate their transfer to and from the boat.

Certain compartments are reserved for carrying the liquid fuel. The principal tank is placed under the floor of the main deck, and the oil is fed to the engines by the aid of pumps. If further fuel tanks are required these are placed, as in the German vessels, in the compartments between the inner and outer hulls, or, as in the case of the Holland submarine, at the extreme stern of the hull, flowing therefrom to the lower tank in the machinery space, whence it is led to the engines upon the pressure-feed system.

There are numerous cylinders, charged to a high degree with compressed pure air or oxygen, for the maintenance of a respirable atmosphere for the crew, and these cylinders are placed beneath the floor in convenient cells in different parts of the vessel. In the latest boats an apparatus is installed for purifying the exhaled air, the carbonic acid gas being absorbed therefrom by means of potash. The purified air is then cooled and re-oxygenated, so that the interior atmosphere of the vessel is always invigorating, cool and healthy. When the vessel first submerges there is sufficient air to sustain the crew for about twenty-four hours, but by means of the supply carried in the compressed air cylinders it is possible to remain below for a much longer period—from forty-eight to sixty-four

hours. By keeping the atmosphere cool and sufficiently charged with oxygen, the crew are able to work for long stretches continuously without experiencing the slightest ill-effects.

Ample supplies of water for drinking purposes also have to be carried, since it has not yet become possible to instal the necessary machinery for distilling potable water from sea-water. The explosion motors are also water-cooled, but the water for this purpose is drawn from the sea outside.

In the early days the quarters within the submarine were severely cramped; the crew were deprived of all comforts; and, generally speaking, their plight was unenviable. If a nourishing hot meal were desired it had to be prepared outside: only cold meals were possible within. But now all is changed, and vast improvements have been effected to ease their lot. Electric cookers enable hot meals to be prepared, while new methods for the preservation of foodstuffs of all descriptions have contributed very materially to the comfort of the men. In fact, owing to the perfection of the canning and other processes, adequate food supplies can be carried on board to keep the crew going for two or three months. In addition, each submarine carries what is known as the emergency ration, which is left untouched until an acute crisis develops.

The interior of the submarine is electrically illuminated, while electric radiators are provided

for heating the vessel. Strange as it may seem, the air within a submarine, after it has been submerged for a time, becomes decidedly chilly. This is due to the low temperature of the water outside, and to the fact that the internal respirable atmosphere is kept at a low temperature, since the air, before being re-admitted into the vessel, passes through radiators which are cooled by currents of sea-water. Again, it must be remembered that the use of electrical machinery for propulsion contributes to such a state of affairs; no warmth is radiated therefrom, as from the explosion motors when the boat is travelling upon the surface.

In the early vessels the crew suffered under another serious disability—the absence of adequate lounging and sleeping accommodation. This defect has also been remedied. The crews now have small saloons as well as comfortable sleeping quarters. In fact, everything that helps to relieve the monotony of the work and the isolation of the position has been freely introduced. The tedium of silent watches under water is even lessened by the inclusion of talking machines and musical instruments!

Wonderful strides have been made in the development of the submarine during the short span of a single decade. Ten years ago the submarine required a complement of only nine or ten officers and men; to-day from twenty-five to forty are necessary for the navigation of the vessel and the tending of its machinery. Of course the crew is

divided into watches, as upon a surface craft, but at times all are on duty simultaneously. The incorporation of special appliances has also demanded the services of special men, such as the operator for the wireless with which every submarine is now fitted. The development of the ocean-going submarine has been responsible, in a certain measure, for larger crews, inasmuch as boats are now able to stay away from port for as long as three months on end; and the day when the submarine will require a complement of eighty men is within measurable distance.

Within the space of this chapter it is impossible to enumerate all the remarkable appliances and devices which are carried upon an underwater fighting ship. There is a testing board for the batteries, a switchboard for the control of the electric machinery, the wireless telegraph operator's apparatus, anchors which are operated by electrically driven winches controlled from within the boat for keeping the vessel steady when lying upon the sea-bed; also there is the fire-extinguishing equipment, since, though the chance of an outbreak of fire on board a submarine is remote, it is quite within the limits of possibility.

In some underwater fighting ships, such as those of the Lake type in the American and German navies, a diving compartment is provided in the bows to enable divers to pass between the interior of the submarine and the sea-bed for planting or

removing mines. This prominent characteristic is described in an earlier chapter. Its inclusion, however, demands that the submarine shall carry a certain supply of mines of convenient size, so that they may be handled without undue effort. The incorporation of mine-laying facilities renders the submarine additionally deadly, since it enables it to fulfil the rôle of mine-layer within certain limits, and to be able to prosecute this work without fear of discovery.

But the submarine is a highly sensitive vessel: its successful manipulation demands highly skilled men. Its stability is constantly varying, and has to be delicately readjusted. While awash, its displacement is continually and steadily diminishing owing to the consumption of fuel, and this has to be counterbalanced by the admission of water. When submerged, its displacement is affected by the firing of torpedoes. These missiles vary in weight from 300 to 600 pounds according to size and class of projectile employed. This weight is released suddenly and compensation therefor must be made immediately by the adjustment of the water within the trimming tanks.

CHAPTER VI

THE ENGINES OF THE SUBMARINE—I. SURFACE PROPULSION

Owing to the absence of suitable engines for propelling their craft the pioneers of submarine navigation were long thwarted in their efforts to realise the apparently impossible. The conditions which had to be met were peculiar: energy was required for two widely divergent purposes; two diametrically opposite conditions had to be fulfilled. These were movement upon and under the water respectively. The first consideration did not hinder development; it was the means of moving the vessel under the water which became the crux of the whole problem.

As the idea developed, one fact became only too patent. Two distinct systems of propulsion were imperative to meet the two conditions of travelling and here was a new field for experiment. This was to discover a propelling system capable of application with equal success to the necessities of both: a system which could be used either for surface or submerged travelling as required. This was where the experimenters encountered galling failure, if they were not completely baulked.

The steam engine was perfectly suited to driving the submarine upon the surface, since the interior of the boat could be opened to the atmosphere while cruising, while by adequate ventilation the working space within could be kept cool so that the crew suffered no undue fatigue. But for underwater work the steam engine was absolutely impracticable, although ingenious efforts to utilise a closed system were made, and, in fact, are being continued to this day. In the attempt to solve this complex issue the application of electric propulsion to the two requirements was subjected to practical test, but proved equally impossible. Unless an enormous battery plant were installed, one far too huge for the limited space available within the submarine, no effective radius of action was possible, while, moreover, the surface speed was far too low to render the arm of any naval value. Consequently the idea of utilising electric propulsion as a common system was abandoned, although it was appreciated that, in the light of existing knowledge, it would have to be retained for underwater movement, a theory which prevails to this moment.

As already mentioned, the submarine owes its development to the present stage of perfection and reliability to the selfsame factor which enabled dynamic flight to be brought within the realms of practicability. The force which contributed so effectively to this end was the appearance of the

high-speed internal combustion engine using gasolene or petrol as fuel.

All the early practical submarines of the present era depend upon this type of prime mover, and, in fact, in the United States it obtains to this day, although with other Powers it has been superseded by a superior engine which has proved far more suitable for this special duty.

The first submarines built for the British Navy—the famous "Hollands"—were fitted with four-cylinder vertical engines which were made in the United States, British builders in this field being at that time unable to meet the situation. The subsequent vessels were engined with sixteen-cylinder Wolseley horizontal motors developing 550 horse-power, but after these boats had been in service for a short period four cylinders were removed, the aggregate output thus being reduced to 500 horse-power. In the later classes, however, a reversion to the sixteen-cylinder motor was made, the dimensions of which were gradually increased until the output reached 850 horse-power, which was sufficient to give the vessels a surface speed of 16 knots.

While the petrol or gasolene engines gave complete satisfaction, they possessed certain features which militated against their popularity. One of the strongest of these was that of fuel. Its susceptibility to volatilisation at normal temperatures constituted a serious menace, especially within

the confined space of a sealed submarine. The gases were not only deleterious to the health of the crew, but, being explosive, were a constant source of danger.

While the accurate determining of the correct proportions of gas and air necessary for the preparation of a perfect combustible mixture was a matter of comparative simplicity, the difficulties of storing the fuel so as to prevent leakage of gas were considered to be insuperable. The vapour, being materially heavier than the atmosphere within the submarine, at first settled in the lowest nooks and corners of the boat. But as it readily combines with the free air and consequently became diffused, there was the ever-present danger that the atmosphere within the vessel might reach the danger mark and be fired by a spark from the electric machinery. Every precaution that human ingenuity could contrive was taken, but the contamination of the atmosphere could not be avoided.

The fate of the petrol motor, so far as its application to the submarine was concerned, hung in the balance for a considerable time, but at last it was decided to abolish it. This action was influenced in a great measure by many factors, such as the growing scarcity of the fuel, its tendency to rise to an artificial price, the uncertainty of its supply, and its deterioration in specific gravity. In Germany the submarine petrol motor never was regarded with favour: its disadvantages were appreciated

from the beginning, and accordingly Teuton manufacturers and inventors were stimulated in the effort to perfect an engine which could use a much heavier and therefore much less dangerous oil.

In some quarters thoughts turned toward the next group in the scale of liquid fuels derived from petroleum, but which are less inflammable. This is the paraffin, or, as it is termed in the United States, the kerosene group. But there are many objections to this liquid fuel, notably the difficulty of vaporisation, the liability of the engine to become choked with carbon products arising from imperfect combustion, and the impossibility of starting up an engine from cold. This last difficulty has been overcome by two methods. The one is to start up the engines on gasolene, and directly the vaporisation of the paraffin commences to switch on to the latter fuel. But this practise introduces the very factor which it is sought to eliminate—the conveyance of gasolene. The alternative is to start up the engine with the electric motors, heating the air electrically, thus bringing the paraffin vaporiser into play, and then switching over as before. The great objection of this latter solution is that if the batteries are run down the engine cannot be started, while the life of the battery is reduced as a result of this application of the energy. Furthermore this use of electric energy reduces the radius of action and submersion period of the

submarine to the extent of the current consumed to start up the engines, a point that might be of vital import.

When the question of retaining or abandoning the gasolene motor was under discussion, attention was attracted to a new engine, which promised to revolutionise the whole problem. This was the Diesel motor, running on the heaviest oils. Here was an engine which was not only free from the liability of explosion, but which promised to prove more convenient and cheaper in operation. The one difficulty, however, was the comparative slowness with which it was developed. The germ of the idea was acknowledged to be promising, but many complex and harassing technical questions arose in bringing the engine to a state of efficiency, reliability and durability. Nevertheless, the issue was attacked energetically by the foremost technicians in the various countries. In this way the objections were overcome one by one, while improvement followed improvement so rapidly that at last the engine was brought to the practical and commercial stage. The first British submarine to carry the Diesel motor was the *D1* of 1907, the motors of which developed 1,200 horse-power, or twice the power developed in any preceding British submarine. This experiment proved so completely successful that the Diesel motor ever since has been adopted by the British authorities for the surface propulsion of submarines, while it has been adopted

by every other power with the exception of the United States. Even the latter Government is tardily acknowledging the superiority of the Diesel engine by equipping the latest boats therewith.

While the Diesel engine is more complicated than its gasolene contemporary and, therefore, demands greater attention in relation to certain factors, the *modus operandi* is extremely simple. At the commencement of the compression stroke the cylinder is filled with air at atmospheric pressure, that is 15 pounds per square inch. This charge is compressed by the rising piston to more than thirty atmospheres, or approximately 500 pounds per square inch, at the top of the stroke. As is well known, the compression of air causes it to heat up, and in the cylinder it attains a temperature of about 1000 degrees Fahrenheit. At this moment a valve opens and a small quantity of heavy oil is driven into the cylinder in the form of a fine spray by a jet of air. The charge is injected at a pressure exceeding that obtaining in the cylinder. The result of forcing the atomised oil into the heated air within the cylinder is to bring about its combustion. This, in turn, causes the air within the cylinder to be raised to a still higher temperature—about 3000 degrees Fahrenheit—with the result that the pressure exerted upon the piston is increased about sixfold. This enormous pressure forces the piston down with increasing velocity in precisely the same way as the piston of the gasolene engine is

driven downwards by the ignition of the gaseous charge.

One point particularly is to be observed. In the Diesel motor there is no explosion such as takes place in the gasolene engine. Its method of working may be said to be more closely allied to that of the hot-air engine. The oil in its atomised form, which is virtually a vapour, is not fired by an electric spark. Combustion is brought about by the injection of the oil into an atmosphere which is sufficiently hot, and it is the expansion of the air within the space, and consequently the enormous increase in its pressure, which forces the piston downwards, instead of a sledge-hammer blow such as an explosion produces. A fresh charge of pure air is admitted for each compression-charge, all traces of the previous combustion-charge being swept out of the cylinder by what is known as a scavenging air-charge, which is driven into the cylinder by means of a pump.

The outstanding advantages of the Diesel motor are its slow running as compared with the gasolene motor, and the circumstance that heavy oils are suitable as fuel. Consequently it is a cheaper engine to run, so far as fuel is concerned. While it does not possess the extreme simplicity of the high-speed explosion motor it is just as easy to manage. Furthermore, the principle of operation can be applied to either four- or two-stroke engines. Lubrication and cooling were two of the greatest

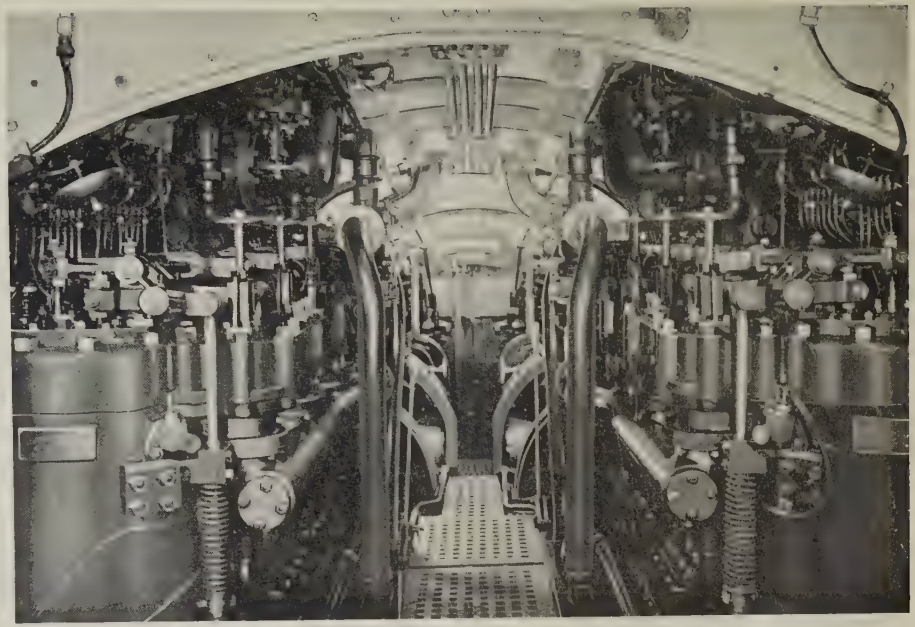
troubles which had to be overcome, but these difficulties have been satisfactorily solved, with the result that the Diesel motor of to-day is as perfect as that which it has superseded.

The perfection of the heavy-oil motor has enabled the engine power of the submarine to be increased enormously. Whereas the first British submarine, built in 1901, had engines developing only 122 horse-power, those of to-day develop 5000 horse-power or more. Space for space, engine powers have been attainable with the Diesel engine which would have been impossible with the gasolene motor. All risk of fuel vapour explosion has been eliminated, while there is no risk of vitiating the atmosphere within the vessel with fuel vapour fumes harmful to the crew.

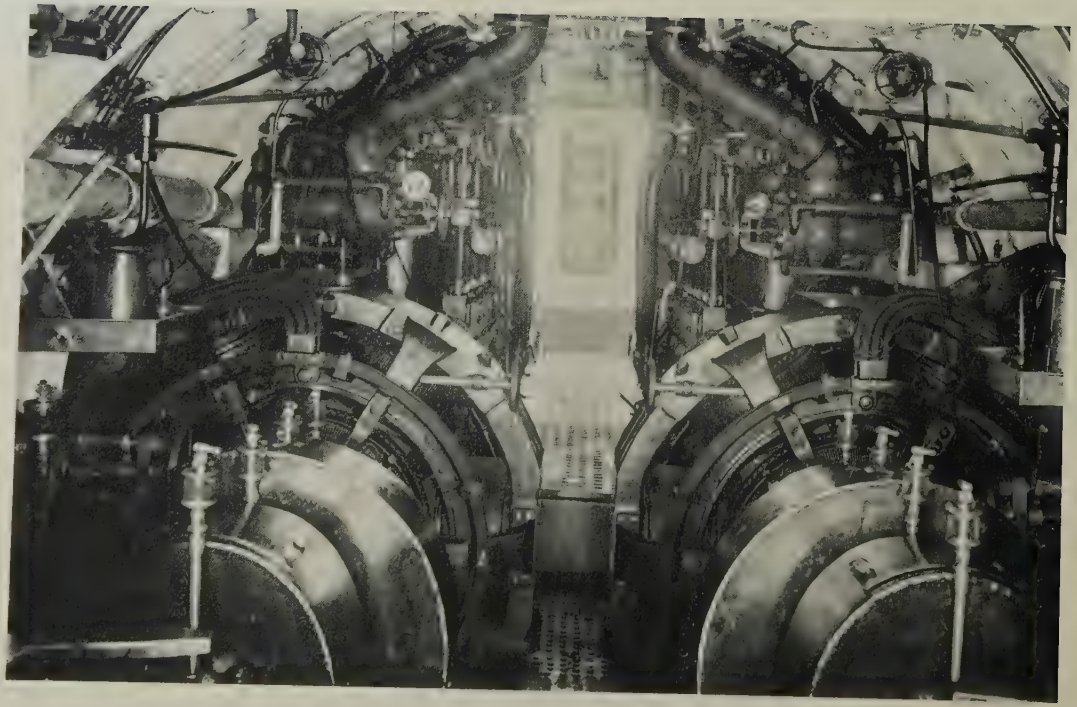
In so far as the development of this motor is concerned, the greatest contributions to its improvement have been made by German engineers and engine-builders. This result was due primarily to the official German decision to use heavy-oil engines exclusively in submarine craft when it was definitely decided to introduce the *unterseeboote* as a fighting unit into the Teuton navy. The Admiralty decision was a direct incentive to further research and experiment, and many of the leading engineering concerns of the Vaterland concentrated their energies upon this task. The naval determination was logical. The Diesel engine had become established as an approved type of prime mover

in stationary installations, and in these circumstances there was no valid reason why it should not be adapted to marine requirements.

There was another powerful reason which directly influenced the course taken by the German Admiralty. Germany is deficient in native petroleum resources: she depends entirely upon her imports of this commodity. This was a serious disadvantage which, in time of war, as the authorities recognised, would affect the nation very seriously. But Germany has ever been an enthusiastic believer in the utilisation of coal gas for power and heat. She possesses enormous deposits of coal, especially in Westphalia, and although in its raw or solid condition this fuel is of indifferent quality when compared with British or American coal, yet it is particularly serviceable for the manufacture of gas. Accordingly the production of coal gas for manufacturing purposes was undertaken upon a comprehensive scale—larger than any that has been attempted by other industrial nations. The outcome of this practice was the production of vast quantities of a by-product which constitutes an excellent fuel for engines such as the Diesel. As is well known, the production of benzol in Germany has been reduced to a huge commercial enterprise, but this rival to gasolene is only one of many articles which are adapted to the internal combustion engine. The two- and four-cycle Diesel engines, with which the German submarines are equipped,



Oil Engines for Driving the Submarine upon the Surface



ELECTRIC MOTORS BY WHICH THE SUBMARINE IS PROPELLED WHEN SUBMERGED
The necessary current is drawn from storage batteries or accumulators.

are adapted to run practically on " waste " products of the gasworks and the oil refineries. Crude mineral oils, while serviceable, are not recommended, owing to the fact that they contain mineral elements and asphalt which are liable to affect the smooth running and reliability of the engine to a very pronounced degree.

The general lines of the Diesel submarine motor are not widely dissimilar from those of its gasolene rival. The weight, per horse-power, varies from 25 to 40 pounds according to whether the engine works upon the two or four cycle, and the duty for which it is intended. The multi-cylinder practice is adopted, eight or more cylinders being applied to each shaft. For heavy and exacting work, such as the driving of submarines, the weight averages about 100 pounds per horse-power, but this includes all the necessary auxiliary plant. When the direct issue of construction for submarines arose, the German manufacturers, owing to the lead they had obtained, were in a distinctly advantageous position and engine sets developing 2000 horse-power were readily built.

While the Germans were evolving these high-powered installations for submarine operations another nation was equally diligent and recorded just as commendable and distinctive progress. This was Italy. Among her pioneers in this commercial enterprise was the Fabrica Italiano Automobil Torino, colloquially known as the F.I.A.T.,

whose achievements in connection with automobiles have a worldwide reputation. This company concentrated its energies upon the construction of two types of the Diesel motor, the one of relatively high speed, especially for submarines, and the other for slow-moving surface craft such as freight boats.

France subsequently followed the movement and evolved a distinctive type of Diesel engine, but in Great Britain developments in this direction were slow and uneventful. Finally the Vickers Company, who held a virtual monopoly in the building of the British submarines, appreciating the fact that the Diesel motor was the ideal prime mover for the surface propulsion of underwater fighting craft, centred their energies upon its perfection for this duty, so that Great Britain should be able to maintain her lead in a highly specialised branch of naval engineering and science. Strange to say, the United States, which has always been regarded as the most progressive and enterprising nation in the world, did not take kindly to this motor, but has clung to the old-fashioned and dangerous gasolene engine.

The Diesel engine can be coupled direct to the propeller shaft, thereby dispensing with the complicated reducing gear. The engine can be reversed, which is a distinct advantage not possessed by its gasolene competitor. A vessel can be put from " full speed ahead " to " full speed astern " in five seconds. Furthermore, the control of the engine is such that the revolutions of the motor may be

educed to one-third of the maximum speed, so hat the speed of the vessel can be varied within vide limits, thereby enhancing its manœuvring apabilities.

The engine is easily started, demanding neither emporary recourse to a volatile fuel such as is ecessary with the paraffin motor, nor the assistance f the electric installation. It is set in motion by he aid of compressed air, the initial impetus being iven from the compressor, which serves to inject he atomised oil into the cylinder after the engine as been set going.

At the moment the Diesel engine is universally cknowledged to be the most successful means of ropelling the submarine upon the surface of the vater. Virtually it possesses all the advantages f the gasolene motor with none of its defects as vell as much of the flexibility of the steam engine. t is economical in fuel consumption. Its control is imple, so that it is not necessary to carry a larger rew than would be essential to tend a gasolene notor of equal power; and it is generally believed hat it will hold its own in this field until another evolutionary idea is evolved and perfected. At he moment there are no signs of the advent of uch a new and formidable rival, and thus the evelopment of the Diesel engine for submarine ropulsion upon the surface is proceeding apace.

CHAPTER VII

THE ENGINES OF THE SUBMARINE—2. UNDERWATER PROPULSION

WHILE the machinery for driving the submarine upon the surface has undergone considerable and remarkable development, the means employed for submerged propulsion has never varied. To-day, as fifteen years ago, electricity remains unchallenged in this field, and its position appears to be assured notwithstanding the many ingenious efforts which are being made to supersede it.

Electric propulsion of the submarine as it is practised to-day possesses certain disabilities. These are recognised and frankly acknowledged. But at the same time there is no other system which has its many outstanding advantages. The machinery is practically noiseless, only a low musical hum being emitted even when it is being pushed to its maximum; there is no pollution or heating of the atmosphere within the vessel, neither is the air available for respiration deprived of any of its oxygen; it is extremely simple to manipulate and to maintain; there is a conspicuous absence of vibration; the lives of the crew are not endangered in any way; while the risk of breakdown has been

educed to the absolute minimum. The accepted nd proved means of driving the submarine under the ater are as reliable as those adopted for propelling upon the surface.

The motors are driven by current derived from econdary batteries or accumulators which are ored below the main floor of the machinery space. he latter are of the conventional lead type although f large size, the cells in the latest vessels being ther in the nature of small vats. The cells, which re placed within a lead-lined tank, are made of ard rubber or some other similar non-combustible ubstance and contain the diluted sulphuric acid r electrolyte and plates. Special attention is evoted to the construction of the tank or outer cket, since it must prevent any of the electro- te, which may be spilled from the cells, from caping.

Should the electrolyte find a crack in the lead nk it would immediately attack the steel plating f the adjacent ballast tanks, fuel tanks, bulkheads, r possibly the main shell of the vessel. This acid- ectrolyte is one of the unavoidable defects of the isting electric propulsion system, since it may ecome a source of serious danger. If it should eet with any sea-water, the sulphuric acid im- ediately attacks and decomposes the salt water, roducing the extremely dangerous chlorine gas. gain, should the escaping solution attack the asolene tanks—if gasolene motors are used—it

is quite possible that it may lead to the release of the gas of that volatile fuel. So far as the British, German, French, Italian and Japanese submarines are concerned, the latter danger has been eliminated, as already explained, by the abolition of gasolene as the fuel for the surface-propelling engines, so that this issue no longer arises with these Powers. But the risk of the generation of chlorine gas within the vessel still remains, though even this danger has now been reduced to an insignificant degree by improved construction of the battery elements and by the adoption of adequate measures to prevent the escape or spilling of the electrolyte.

In earlier days, the chlorine gas trouble assumed somewhat alarming dimensions, and when this gas mingled with the fumes of the escaping gasolene, which occasionally occurred, the situation within the vessel became extremely unenviable, if not precarious, to the crew. The detection of the traces of chlorine gas were somewhat difficult, and it was in order to safeguard the crews of British submarines against this invisible foe that white mice were billeted on the vessels. The latter are particularly sensitive to the poisonous effects of this gas, the presence of which even in small quantities was revealed by their succumbing to asphyxiation. Those days are commemorated, so far as the British underwater fighting vessels are concerned, by the prominent figures of these animals upon the submarine flag, above the motto *Qui*

ıb mare in navibus descendunt, "who descend eneath the sea in ships."

The serious danger arising from imperfectly esigned and constructed cells for the electrolyte as brought home very vividly to the American avy Department in the autumn of 1914. Sub-arine *E2* was making her way from Newport ews to New York when the crew was suddenly bserved to be in distress. The symptoms pointed " gassing " and prompt measures were at once ken for their relief. It was then ascertained that e spilled electrolyte had escaped from the lead-ned tank, and coming into contact with sea-water, e production of chlorine gas had ensued, the rcentage of gas reaching a dangerous figure.

This discovery prompted the overhaul of the nks of the other submarines and a disconcerting tuation was discovered upon a second vessel. In is instance, the electrolyte had attacked one of e gasolene tanks and had corroded the metal. nis offered a vent for the gasolene, which was found appreciable quantities in the battery tank itself. ne discovery was made none too soon, for the mosphere was found to be sufficiently impregnated th the gasolene vapour to be highly inflammable.

But the greatest disability of the electric pro-lsion system is the limited submerged radius of tion of the vessel upon a single battery charge. this respect there is a total absence of that sticity which prevails with the surface-propelling

system. In the latter instance the radius of action can be and, in fact, has been increased tremendously by the storage of additional quantities of oil. But this is a much simpler procedure than that of increasing the radius of the electric propelling plant, because this can be achieved only by augmenting the battery. Fuel oil can be carried in the space between the inner and outer hulls, but the increase of the battery entails encroachment upon the working space of the vessel, which already is somewhat cramped and could in no way be reduced. The early Hollands, built in 1895, could only travel under water for four hours at their maximum submerged speed of 5 knots, which represented one-tenth of their radius of action when moving upon the surface. Even the first British vessels could only cover 46 miles under water when travelling at the reduced speed of 5 knots. If driven at the full speed of 7 knots continuously, the radius of action was reduced to 25 miles.

But as the dimensions and formidable character of the submarine were increased so were the power and radius of action of the machinery for underwater propulsion augmented, until to-day the latest vessels are able to attain a maximum speed of 12 to 14 knots, at which speed the radius of action is approximately 160 miles. The wide divergence between the radii of action upon the surface and underwater respectively—a modern submarine is able to cover 5000 knots at reduced

peed—may appear to nullify the value of this ype of craft, but the fact must be borne in mind nat, notwithstanding its name, the submarine is ormally intended to travel upon the surface. As xplained elsewhere she merely submerges to ttack, to take cover, or to seek sanctuary upon ne sea-bed until the threatened danger has assed.

The size and horse-power of the electric motors f the submarine have been steadily and persistently ncreased to keep pace with the augmentation of ne dimensions and displacement of the craft and the ower of its surface-propelling machinery. In the nodern vessel the maximum energy developed by ne electric motors, when the boat is travelling ubmerged, is equal to that of the surface-driving nachinery of five years ago. Yet perfection has ot been attained. The ideal submarine according o the views of the foremost designers is one apable of travelling from 20 to 24 knots upon ne surface and at a minimum speed of 16 knots hen submerged. There is every indication that uring the present war these desiderata will be lfilled, inasmuch as development is proceeding at quicker pace than was the case during times of eace.

In order to increase the radius of action under- ater, a search is being made for an improved type secondary battery. Owing to the success of the dison accumulator upon land the possibility of

adapting it to the conditions required for the submarine are being seriously considered. Indeed, during the spring of 1915, experimental runs with an American submarine equipped with the Edison battery were made for the purpose of collecting definite and comparative technical data bearing upon this issue. Should it be proved possible to apply this battery to submarine propulsion it will undoubtedly mark a forward step of considerable import.

The storage battery perfected by the eminent American inventor differs radically from that which has been in vogue for so many years and which is so familiar. In one respect it is superior, since with its use there is no risk of the crew being asphyxiated, because, instead of using a sulphuric electrolyte with the danger of forming chlorine gas in the event of leakage and contact with sea-water, an electrolyte of potassium hydrate, with which a small quantity of lithium hydrate is associated, is used.

The fundamental principle of this battery is the oxidation and reduction of metals in the foregoing electrolyte, which, however, will not combine with them or their oxides. The positive and negative elements comprise nickel and iron respectively, but not in their metallic state. The positive element comprises nickel hydrate, while the negative element is iron oxide, and both are carried in perforated tubes which are packed, or disposed, in

ıch a manner as to fcrm a grid to permit the free ow of the electrolyte around them.

This battery possesses many features the value f which has been conclusively established. It as a pronounced advantage in weight, has a long fe, is nót readily damaged, and can be short-rcuited and subjected to other indignities which ould spell ruin to the ordinary lead-sulphuric acid ell. It has the additional advantage of being osolutely safe. Should any chlorine gas be gen-rated as a result of the decomposition of sea-water y the passage of the electric current, it is converted stantly into iron chloride, owing to the affinity f iron for chlorine, this chemical reaction being ue chiefly to the fact that the jar or cell is made f steel, while this metal also enters largely into the onstruction of the plates.

The electrolyte used in this battery performs nother useful function. By its aid the atmosphere ithin the submerged submarine may be kept in purer and sweeter condition. The carbonic acid as given off by the respiratory organs of the crew eing heavier than the air, settles to the floor, and absorbed by the cells, which contain sufficient otash to fulfil this duty for about one hundred ays. Whether the Edison battery will establish s superiority over the popular lead-sulphuric acid ell remains to be seen, but up to the present the tter remains in favour, since it is claimed by those ho are intimately associated with the submarine

and all its developments to possess qualities which are alleged to be deficient in the Edison rival.

Although the electric system of propulsion underwater is practised by all the Powers, it must not be thought that it goes unchallenged. Mechanical ingenuity and inventive fertility are actively engaged in evolving and perfecting a propelling system which may be used with equal success when the vessel is travelling submerged and when cruising on the surface.

In 1913 there appeared a small submarine, displacing 43 tons, which was built from the designs of Mr. John M. Cage, of Long Beach, California, U.S.A., the distinctive feature of which was the use of one set of gasolene motors, developing an aggregate of 220 horse-power, both for surface and submerged propulsion. By means of a special device it was stated that the engine exhaust could be expelled overboard without any difficulty up to a depth of 300 feet, and without vitiating the atmosphere within the submarine to the smallest degree. According to test runs which were made, the gas fumes were exhausted against a back pressure—the pressure of the surrounding water—of 12½ pounds per square inch, and in one instance the valve on the outboard exhaust was screwed down until the motor exhausted against a back-pressure of 150 pounds. This latter figure corresponded to the hydrostatic pressure which is experienced at a depth of 342 feet.

Unfortunately, however, there is one decided drawback to the use of such a system upon a submarine designed for naval work. The exhausted gases are certain to make their way to the surface in order to escape into the air. This action must be attended by a certain degree of agitation in the water. Accordingly it would be a simple matter to stalk a submarine which depended upon such a system of propulsion when submerged, because its line of movement would be visibly revealed upon the surface by a wake of bubbles caused by the rising gases of combustion exhausted from the engine.

Although the radius of action of the submerged submarine upon a single battery charge is somewhat limited, the accumulator may be recharged at sea, and thus be kept "well up" to its assigned duty. When the vessel comes to the surface the motors are coupled up to the cruising engines and the battery is submitted to a period of charging. In fact the accumulators are kept in the fully-charged condition as far as circumstances will permit. In the case of a submarine to which is delegated a specific duty, such as lying in wait for an expected vessel, and which takes the precaution of rendering herself invisible by lying upon the sea-bed during the hours of daylight, the charging of the batteries is performed under cover of darkness, when the vessel comes to the surface to maintain her vigil.

CHAPTER VIII

THE PERISCOPE, THE EYE OF THE SUBMARINE

THE many sensational performances which have been placed to the credit of the submarine during the great war have created something approaching consternation among the timorous. To them it appears to be extraordinary that such a relatively puny craft should be able to sight and to approach such a vessel as the *Lusitania*, for instance, and to be able to launch her deadly missiles without detection by any one on board her prey. The ability to steal upon the objective under water with unerring precision appears to savour of the mysterious and the uncanny. Why should the submarine be able to spot its quarry and yet remain invisible?

Yet there is nothing mysterious about the operations of the submarine. Her movements are not uncanny. Her commander, when 10 or 15 feet below the waves, knows precisely where he is going and what he is doing, as well as all that is transpiring above the surface of the sea. The submarine is equipped with an organ of vision of which full advantage is taken, and upon which the man in charge of the little craft centres his entire

thought and attention. Certainly his surroundings contribute towards such concentration: there is no distraction, and it is fortunate for him that such is the case, otherwise disaster swift and sudden might overwhelm him.

The eye of the submarine is truly a wonderful illustration of human ingenuity and science. It is by no means a modern invention, for it has been known under a variety of names at different times, such as the omniscope, hyposcope, and so forth, although to-day it is virtually known throughout the whole world under one distinctive title—the periscope.

So far as is known, the first attempt to apply the periscope to underwater navigation was made in 1864, at which time there was a marked recrudescence of activity among inventors towards the solutions of this problem. It was a crude contrivance, comprising a tube, at the upper and lower ends of which plane mirrors were set at an angle of forty-five degrees to the perpendicular. The uppermost mirror caught the picture of the scene immediately confronting it, and reflected the image down the tube into the second mirror where it could be viewed with ease. The periscope of those days resembled the device at present in use in the trenches upon the battlefield of Flanders. It was effective up to a point, but it suffered from the disability of reflecting but a small part of the picture and that somewhat indistinctly. Such a system, moreover,

demanded a wide and relatively short tube, which handicapped the evolutions of the underwater vessel.

But it was upon this foundation that the periscope, as it is now known, was built, though the modern instrument has no more resemblance to that of a half-a-century ago than the express locomotive bears to the " Rocket."

Plane mirrors were superseded by totally reflecting prisms, and these in turn gave way to a combination of prisms and lenses. Whereas the first periscope comprised a straight vertical tube containing only two pieces of glass, the instrument of to-day consists of a tube, also vertical, containing perhaps as many as seventeen optical implements. Thus it will be seen that it has been transformed from a simple piece of mechanism into a highly complicated apparatus, in which excellence of workmanship is demanded in order to constitute an infallible guide to the men in the vessel moving beneath the waves.

The tube containing the prisms and lenses is about 20 feet or more in length, and extends from a point within the conning tower, through the roof of the latter, to a point above the water. The carrying tube is of great strength and is mounted within an outer tube or sheath. This is a fixture, and is provided merely to facilitate the rotation of the periscope tube proper. In the early days the periscope tube was fitted in a watertight stuffing-

ox in the roof of the conning tower, but this practice as far from satisfactory. While the tube could e turned round and round to sweep the horizon ithout any difficulty when the boat was stationary, was extremely difficult to rotate when the boat as moving, because the resistance offered by the be to the water caused the latter to force the tube ckwards and thus induced it to bear tightly upon ie side of the stuffing-box, the result being that it uld be turned only with difficulty and in a jerky anner. By providing a heavy outer sheathing be which is sufficiently strong and rigid to resist is backward pressure of the water, the periscope oper may be rotated without effort and steadily. also enables the eye or inner tube, with its lenses d prisms, to be withdrawn into the boat when e occasion demands.

The broad principles of the periscope may be ore readily understood by referring to the accom-nying diagram (Fig. 1). The upper end of the be terminates in a hood which is fitted with a nall lens or objective A, set vertically in one wall, rough which the image passes to be reflected in ism P_1. The rays of light forming the picture e bent through an angle of 90 degrees by this ism so as to be thrown down the tube. On so ing they pass through the series of lenses, O_1, U_1 d U_2, into the lower prism P_2, where they are again nt through an angle of 90 degrees to enable e image to be seen in the eye-piece O_2 from a

natural or upright position by the observer within the vessel.

As every one who has practised photography knows, an image caught by the objective or lens is inverted. In the camera it is thrown upside down upon the ground glass. The periscope may be likened to an elaborate photographic camera. Indeed, by the addition of a simple apparatus at the eye-piece O_2, photographs may be taken through a periscope. In submarine observations an inverted image would be useless. The reversal of the picture in the observer's brain so as to obtain a true representative impression of the view outside would impose a severe mental strain, and certainly would tend to confusion and error. Accordingly, the periscope is so made that this disability does not exist. The optician has incorporated a means of reversing the inverted image so that it is presented to the observer in exactly the same manner as it would appear to his naked eye were he above the water. This reversal of the image is carried out by what is known as the " erecting prism " P_2.

The outstanding objection to the ordinary periscope is that only a fraction of the scene can be caught and transmitted to the observer below. This angle of vision ranges up to about 60 degrees—30 degrees on either side of a point immediately facing the centre of the objective A. Seeing that the complete circle comprises 360 degrees, it will be realised that the underwater navigator is only able

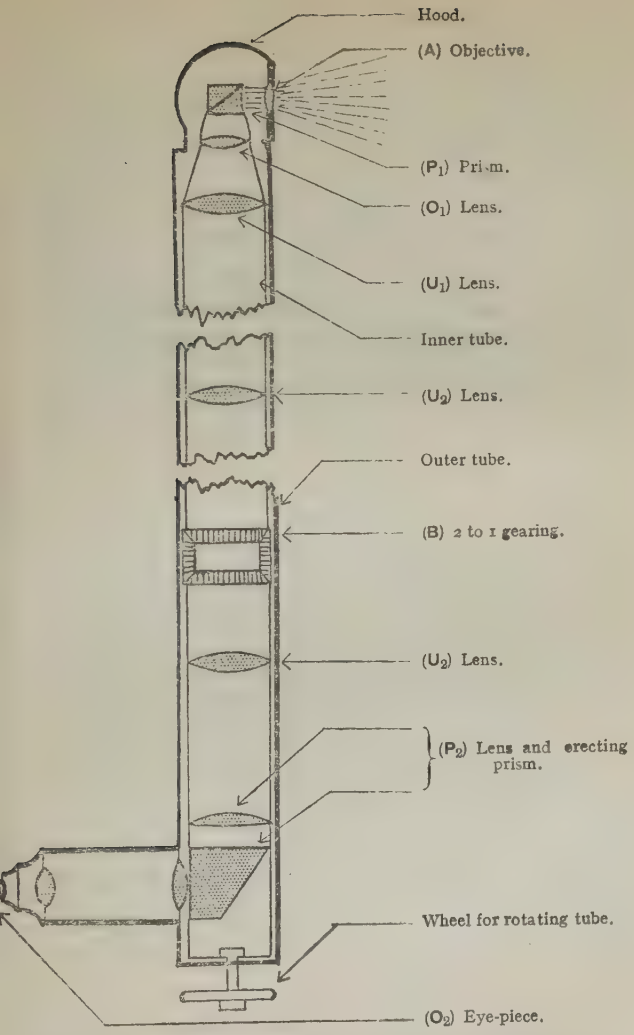
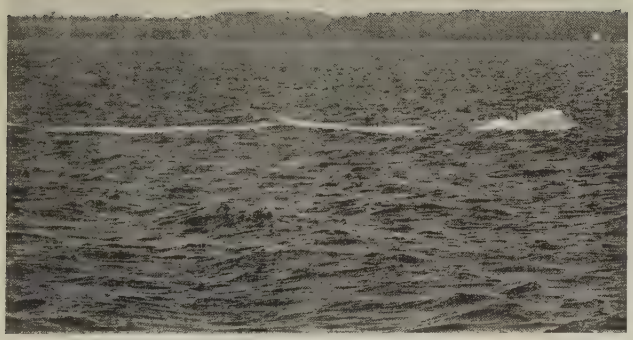


FIG. 1.—THE PERISCOPE—THE EYE OF THE SUBMARINE.

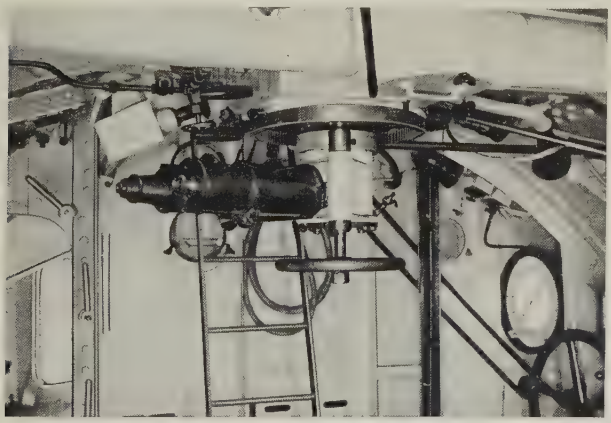
to see about one-sixth of the total area about him at one time. To sweep the horizon the periscope must be revolved. This is accomplished either by means of a handwheel or by the aid of a small electric motor. The top of the periscope revolves, but the lower part of the tube, carrying the reversing prism, also moves, though, owing to the introduction of gearing B, with half the angular velocity of the top, which serves to compensate for the difference of azimuth between the top rotating prism and the lower prism which is fixed.

But the observation of the scene above the water is merely one phase of the duty of the man in the conning tower. His periscope is constantly in movement as he sweeps the horizon on the look-out for an enemy ship. To enable him to steer according to his observations he must be provided with means of ascertaining the direction in which his ship is travelling in relation to his line of sight. It must be remembered that the submarine must be bow or stern on to its quarry in order to launch its torpedo, so that it is absolutely essential that the observer should be continuously informed of the vessel's course. This end is now accomplished by fitting two glass plates within the tube, one being fixed within the revolving section of the periscope, while the other is placed within the fixed part of the tube. The former carries an index and moves naturally with the tube. The latter is inscribed with a graduated circle, and, by observing the



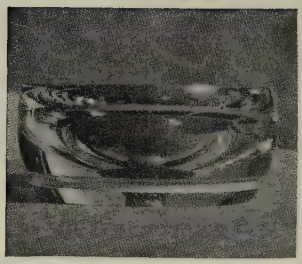
THE EYE OF THE SUBMARINE

At right may be seen the projecting periscope by which the underwater vessel finds its way when travelling submerged.

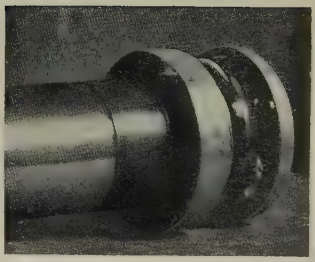


EYE-PIECE OF THE PERISCOPE IN THE CONNING TOWER OF THE SUBMARINE

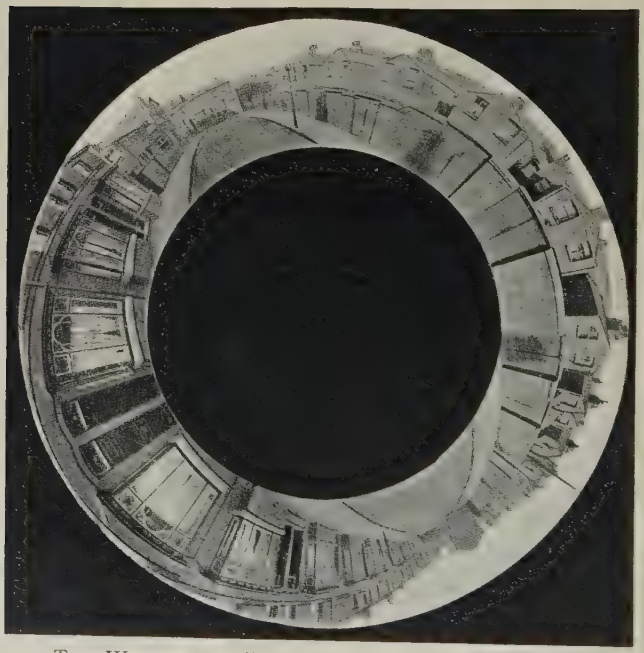
The periscope may be rotated by the horizontal wheel so as to sweep the waters on all sides of the vessel.



The lens unmounted



The lens mounted in its tube



THE WONDERFUL "ALL-ROUND-VIEW" PERISCOPE

The continuous view throughout the 360 degrees of the circle.

ationship of the index upon the one glass to the ibration upon the second plate, the observer is le to determine instantly the exact relation of e line of sight of the periscope with the longi- dinal axis of his boat; in other words, the direc- n in which the latter is moving towards or away m the object sighted.

The magnification with the ordinary instrument very slight, being about 1·5 times, but a magnifica- n to about six diameters can be obtained for a ief period by the use of special devices which are ovided for this purpose. In some instances two riscopes are carried, one giving what might be scribed as a true representation of the view above rough the 60 degrees of vision with little if y magnification, while the second instrument used to afford a magnified picture of any part the image.

But the fact that the periscope's angle of vision confined to 60 degrees in the horizontal plane a severe disability. If the observer's attention riveted upon what is transpiring immediately ead or on either side of the submarine, he is norant of what is taking place to the rear. The bmarine is very much in the position of a horse uipped with blinkers. This was the cause of the lamity in the Solent some years ago. The liner *rwick Castle*, steaming up the waterway, did not e the slender periscope of the submarine ahead her, while the submarine did not observe the

approach of the liner. The result was that the latter blundered into the underwater vessel, ripped her hull open, and sent her to the bottom.

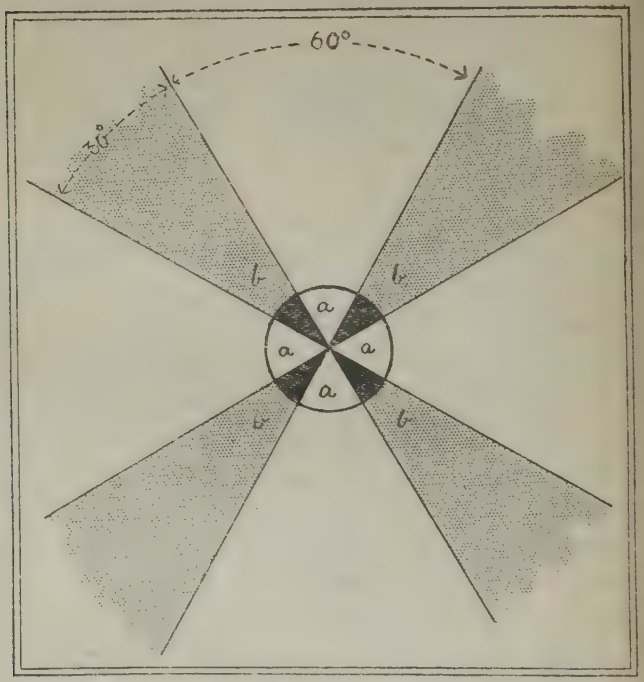


FIG. 2.—MALTESE CROSS, "ALL-ROUND-VIEW" PERISCOPE.
The four periscopes *a a a a* are spaced equidistantly. Each covers a field of 60 degrees, but the periscopes are divided by "blind" sectors *b b b b* each of 30 degrees, a vessel approaching through any of which is safe from discovery.

This drawback was realised the moment the submarine was accepted as a proved fighting unit, and many inventors forthwith attacked the problem with a view to providing the vessel with what may

termed "an all-round eye," or at any rate an
e which could take in more than 60 degrees. One
enious idea was the disposition of four lenses,
the present character, in the form of a maltese
oss (Fig. 2), but even then the navigator was left
protected through 120 degrees of the complete
cle, represented by the blank spaces of 30 degrees,
tween the lenses, and it was quite possible for a
stile vessel to approach through the blind angle
tween two adjacent lenses.

The production of an all-round eye appears to
a simple task, but as a matter of fact it is beset
h innumerable technical difficulties. In fact,
ny optical scientists declared it to be impossible,
at least only feasible by the extreme complication
the apparatus. A British inventor, Mr. H. F.
nston Funnel, attacked the problem, and, by
odigious labour and excessive patience, produced
h an instrument. It was crude and quite im-
cticable, but it contained the germ of a practical
a. He carried his scheme to a certain stage and
n frankly confessed that he could proceed no
ther. It baffled him completely.

But, determined not to be beaten, he introduced
instrument and explained the proposal to a
nd, Mr. T. J. Niblett, M.Inst.C.E., and the two
estled with the problem in co-operation. Certain
gress was recorded, but the engineer appreciated
fact that the crucial points could only be solved
optical science. Forthwith they approached

two young and clever opticians, Messrs. Aldis Brothers of Birmingham, whose recent appearance—at that time—in the photographic lens manufacturing world had aroused considerable attention owing to the quality of their work. They investigated the project, and the very difficulties which were presented appealed to them. They attacked the issue boldly and, after considerable patience and prolonged experiment, they produced a periscope which gave a clear uninterrupted view through the complete circle.

This all-round eye is a marvel of ingenuity and, as had been foreshadowed, is a complicated instrument. There is a special lens of narrow width and of special shape carried at the upper extremity of a phosphor-bronze tube. This catches the view throughout the circle and projects it down the tube to the eye-piece within the conning tower. But during its passage through the tube the rays of light pass through no fewer than seventeen lenses disposed in nests. Each set of lenses performs a distinctive function, such as the correction of distortion, astigmatism, aberration and so forth, the solving of which complexities proved the most searching to overcome.

The view produced by this periscope is shown in the illustration facing page 91. It will be seen that it protects the underwater navigator from being run down from any and every point of the compass. Furthermore, the image is projected

vith such uniform definition and luminosity that mistake in observation is impossible. It will be bserved that in the centre of the picture there is circular blank space. This represents the field mmediately below the object glass, *i. e.* the interior f the tube itself, which of course is not required. A means of turning this blank space to useful ccount was evolved. One suggestion was that it hould be occupied by a floating compass, but the ptical engineers recommended that therein should e given an enlarged view of the path immediately in ront of the submarine, thus combining the limited ision of the ordinary periscope with the all-round iew provided by the improved instrument.

The latest German submarines are fitted with a eriscope of this type, operating upon similar road principles. The main picture, if such it nay be termed, is a sharp magnified image, but this s surrounded by a view of the horizon through he 360 degrees. This last-named view, however, s upon a smaller scale. The periscope whereby his end is achieved carries the ordinary objective, ut above this is mounted an annular lens to give he all-round view.

While observation by the periscope has been rought to a high standard of perfection, duty at he instrument for prolonged periods, without elief, produces pronounced eye strain and fatigue. n very clear weather, and when the conditions o not compel the closest attention to detail, ap-

CHAPTER IX

TESTING THE SUBMARINE

It is safe to assert that no vessel is so imperfectly understood by the average individual as the submarine, and, consequently, many curious and fantastic notions concerning the capacities and capabilities of this vessel prevail even to this day. Probably no topic of popular discussion or argument is so provocative of varied and conflicting views as that concerning the depth to which a submarine may descend in safety. While some people, no doubt influenced by Jules Verne and his imitators, are disposed to invest the submarine with extraordinary powers, maintaining that it can descend to and manœuvre at any depth of water, others fly to the opposite extreme and contend that she is unable to venture below thirty feet or so, and that she really travels with her periscope only just submerged.

Such conflicting views are excusable. The average individual has been compelled, from the absence of scientific details, to accept the submarine as painted by the famous French author, who in this, as in other instances, demonstrated his uncanny

ability to anticipate scientific achievements by romantic fiction. When Mr. Simon Lake's famous pioneer vessel *Argonaut* completed her one thousand miles of submarine travelling, a feat which caused considerable sensation at the time, Jules Verne cabled from his home: "While my book *Twenty Thousand Leagues under the Sea* is entirely a work of the imagination, my conviction is that all I said in it will come to pass. A thousand mile voyage in the Baltimore submarine boat is evidence of this. The conspicuous success of submarine navigation in the United States will push on underwater navigation all over the world. The next great war may be largely a contest between submarine boats." The *Nautilus* of fiction had been eclipsed by the *Argonaut* of mechanical and scientific achievement.

The popular theme of argument to-day was the subject of discussion among scientists and engineers ten years ago. The latter were then almost equally ignorant as to the depth of water to which a submarine, of the form which had been accepted as most satisfactory, could descend, returning to the surface in safety. It was a difficult question to decide positively, since complete decisive experiments were frankly impracticable. In a measure it resembled the debatable issue of the effect of heavy gun-fire upon the turret of a warship and upon the crew within the turret in particular. In both instances a good deal had to be taken for

granted. The experience of war is deciding the gun-fire problem, but that pertaining to the submarine still remains undecided to a certain extent. Many problems of technical significance remain to be settled, but during the past few years contributions of incalculable value have been made, the results of which are reflected in the stronger construction of the vessel and the greater depth at which it now performs its designed evolutions.

In the early days this absence of scientific knowledge was responsible for many mishaps, one of the American vessels in particular narrowly escaping disaster. This boat, by some means or other, had been taken down a few feet beyond that at which she had normally operated. The effect of this slightly excessive submergence and the augmented water pressure proved to be beyond the valves, which commenced to leak. This development in turn induced the vessel to sink lower, and the lower the submarine descended the greater the volume of water which poured into her. At last a depth of 123 feet was recorded, the vessel having been carried down thereto by the water which forced its way into the interior, and which successfully defied the efforts of the commander and crew to regain the surface by the conventional methods. It was only by a superhuman effort—an effort born of desperation at the prospect of the terrible impending fate—that the leak was finally arrested.

The crew worked a single hand pump, and, once they gained the upper hand, it was possible to bring the vessel slowly to the surface. One and all admitted that the escape of the vessel and the crew had been fearfully narrow, and it taught the United States Government a salutary lesson. Further risks of this character should not be incurred: in future, before a submarine was accepted for the navy, it would have to pass through an exacting submergence test.

A more comprehensive and lucid idea of the effect of water depth upon the submarine may be gained by a brief explanation of the conditions which have to be met and of the adverse influences which have to be counteracted. We are all familiar with the circumstance that we, living upon the surface of the earth, have to withstand an air pressure of 15 pounds upon every square inch of our bodies. But we suffer no discomfort, for the reason that this pressure of the atmosphere is exerted in all directions equally upon the outside of the body, and because it is balanced by an equal internal pressure. Consequently, the solids and liquids which comprise the human body enable a perfect equilibrium to be maintained, and this is not seriously affected by slight variations in altitude. It is only when the body is transferred quickly to a point such as a mountain peak, upon the summit of which the air pressure is reduced very appreci-

ably, that physical discomfort is experienced. This is because the air and liquids contained in the flesh of our bodies are exerting an outward pressure of 15 pounds per square inch, whereas the external pressure has fallen below this figure. By the observance of proper precautions the equilibrium, in time, can be readjusted within certain limits.

This decrease of atmospheric pressure proceeds as the altitude is increased, the result being that ultimately the body would be exposed to such a slight external atmospheric pressure and one so decisively overbalanced by the internal pressure as to render physical existence impossible. The blood vessels distended to their uttermost limit would burst.

But the effect in the sea is diametrically the reverse: the outer pressure, that is the pressure of the surrounding water, rises as the body descends lower and lower. The increase in this pressure is approximately ·435 pound per square inch per vertical foot. Thus one would have to descend to a depth of about 34 feet to encounter a pressure of the water corresponding to the pressure of the air above, namely 15 pounds per square inch. The American submarine, when it was forced to the depth of 123 feet, experienced a pressure of 53½ pounds upon every square inch of its external surface, and this was the pressure which the crew had to overcome when manipulating their hand-

ump in order to drive out the water. It is not rprising that, upon their return to the surface, ey bore visible evidences of the physical strain to hich they had been submitted.

The American Government, in debating the uestion, decided to make the test somewhat ex-cting, so as to provide an ample factor of safety. lthough a vessel might normally operate at a epth of 50 feet, if it were built to withstand a ressure three or four times that depth it would e from three to four times as strong and as safe s it need be. Moreover, if the necessity compelled ie vessel to descend to twice the normal depth, oo feet, no risk would be incurred. As a result f the deliberations, it was decided to establish a ibmergence limit of 200 feet. To-day all sub-arines are sunk to this depth in an empty con-tion, that is, crewless, and must demonstrate eir ability to withstand the strains and stresses nposed at such a depth before being accepted for ommission.

To the uninitiated the submergence of a sub-arine to such a depth may not seem particularly fficult, and it may be well to give some idea of ie conditions it forces upon the designer and uilder of the vessel. At 200 feet depth the pressure f the water upon the outer surface of the shell is 7 pounds per square inch. The internal pressure n the other hand is only 15 pounds per square

inch, because the crew work in a normal atmosphere, as if they were labouring in the open air at the surface. Consequently, the steel framework or skeleton of the submarine, together with the steel plates which form the hull, must be sufficiently strong and thick to prevent buckling inwards, or, if they should give under the pressure, must possess sufficient elasticity to return to the former shape when the vessel returns to the surface. In other words there must be no permanent deformation.

The strength of the vessel itself is merely one factor in the issue. The valves which control the immersion and blowing of the ballast tanks must be proof against this pressure. But a point of far greater importance is that the pumps must be sufficiently powerful to act against a back pressure of 87 pounds per square inch.

From a cursory view a pressure of 87 pounds per square inch may not seem excessive, until one reflects upon what it signifies to the whole of the vessel. An interesting comparison may be drawn. If a man's body is assumed to represent a superficies of 2000 inches, the pressure of 15 pounds per square inch represents an aggregate of 30,000 pounds—13 tons—for the entire body. If the man is submerged to a depth of 2000 feet and subjected to a pressure of 87 pounds per square inch the pressure which will be brought to bear upon the whole body will represent no less than

174,000 pounds—over 77½ tons! Bearing in mind the relative sizes of a man and a modern submarine it is possible to form some conception of the enormous strain which a submarine is called upon to withstand during a trial of this character.

The submergence test is completed without the crew because, obviously, it is attended by so much risk as unnecessarily to jeopardise human lives. Two methods of sinking the submarine are practised. One is to trim and complete every preparation for sinking the vessel under normal submerging conditions, the boat being held in this position meanwhile by the aid of cables and derricks. The final task is the sealing of the conning tower. The cable is then paid out, and the buoyancy of the submarine having been destroyed she sinks slowly and steadily until at last the 200-feet depth is recorded. Afterwards the cables are wound in until the submarine regains the surface.

Such a sinking operation, however, is one of extreme delicacy. Dead-smooth water is imperative. Again, there is the risk that the lifting cables may part, in which event, of course, the vessel founders. To guard against this contingency special arrangements have to be made to ensure the return of positive buoyancy to the lost boat. The second method, and one which is now invariably followed, is to anchor special haulage gear to the sea-bed upon the testing-ground, and to attach the cables to the

vessel, which is sealed in the positive buoyancy condition. The hauling gear is set in motion and the submarine is pulled downwards to the required depth. The outstanding advantage of this system is that in the event of the cables parting the submarine does not sink but comes to the surface. Furthermore, little attention need be paid to the weather conditions when carrying out the test by this method.

Upon return to the surface the submarine is opened up and a minute examination of the interior is made to ascertain whether any defects have developed. Nothing untoward being apparent, the vessel, other official trials of varying character proving satisfactory, passes into the navy. The first American submarine to be submitted to this test was the *Octopus* (*C1*), which was submerged to a depth of 205 feet off Boston, on June 8, 1907, from which she emerged with complete success.

The fact that a vessel has passed successfully through the official 200-feet submergence test induces the crew to place unwonted confidence in their boat, with the result that deep-sea manœuvres are essayed without the slightest hesitation. Indeed, in the American Navy there is a manifestation of keen rivalry in the creation of what may be described as depth records. Thus, for instance, the Lake submarine *Seal* (*G1*) established a record by descending to 256 feet. But this distinction

as wrested away by the *F1*, which, during a six ours' submerged cruise in San Francisco Bay, avelled for ten minutes at a speed of 6 knots a depth of 283 feet. At this level the water essure is no less than 123 pounds per square ch.

The naval administrations of the various powers roughout the world have established individual bmergence tests which have to be fulfilled before vessel is commissioned. While these tests vary mewhat widely, one and all are carried out at a pth which it is calculated as being adequate to duce the revelation of any structural defect if ch exists. Thus, in the German Navy, the boat sent down to a depth of about 170 feet and has to main in that position for a prescribed period. In me instances this duration of submergence exnds to two hours or more, so that ample oppority is afforded for the development of any rmanent deformation incidental to structural eakness or faulty design.

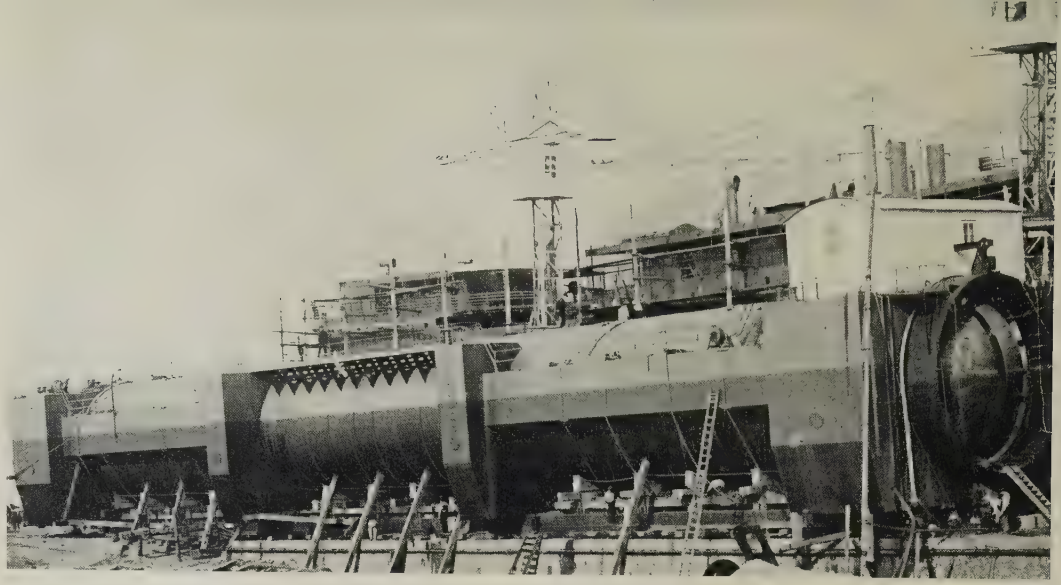
But submergence tests carried out upon such lines e only partially conclusive. There is one serious sability. The boat is sent down empty: that is say without any observers to follow the operations d to record exactly what takes place while the at is passing through the ordeal. If any leakage ould occur it is impossible to say at what depth first became manifest. Of course, after a sub-

marine has issued from the trial successfully it is only logical to infer that it can be sent down to such a depth again and with the crew on board, but normally a submarine does not descend beyond 100 feet.

In order to remove this disadvantage the eminent Italian naval architect, Major Cesare Laurenti, whose type of submarine now figures in every Navy of the world, designed what he terms a testing-dock, by means of which observation of the points at issue may be made in safety and in such a manner as to offer material assistance to the designer and constructor of the underwater fighting ship.

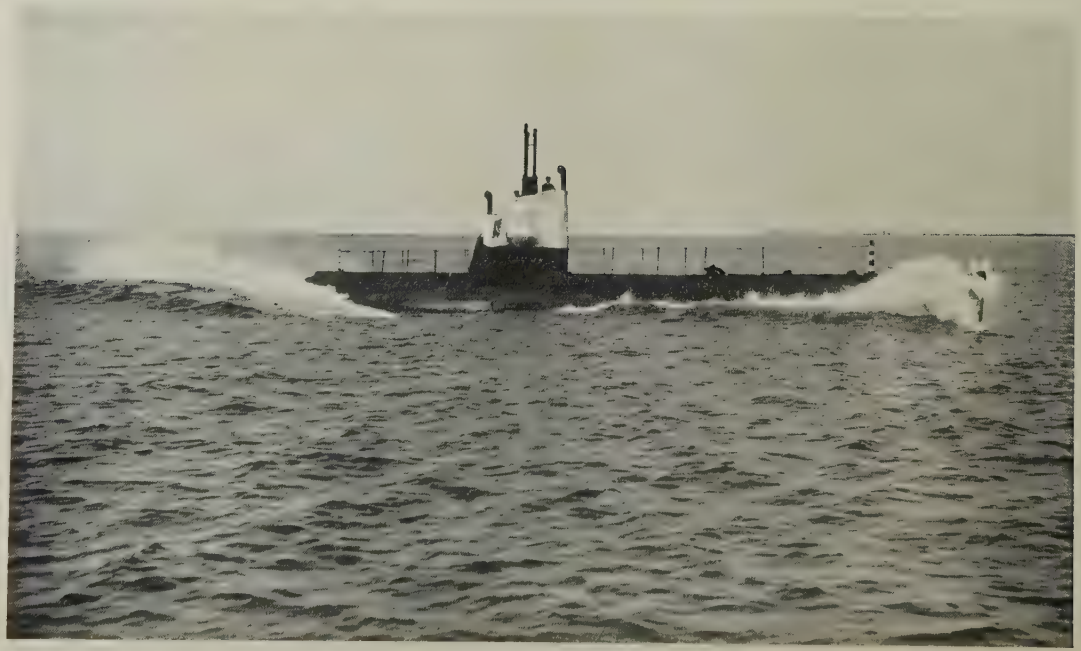
The testing-dock is of simple construction, comprising a huge cigar-shaped cylinder of steel, 233 feet in length, by 36 feet beam, and 24 feet in height. In the empty condition it displaces 500 tons. It is permanently closed at one end, while the other is fitted with a huge globular stopper or caisson, hinged so as to swing in the manner of a door. The cylinder is supported by a series of ballast tanks to and from which the water can be admitted or expelled as required.

The operation of the dock, so far as loading and unloading are concerned, resembles the practice with ordinary floating docks. The dock is lowered into the water by opening the ballast tanks. When the required depth has been reached the hinged caisson is opened and the submarine, resting awash,



A Dock for Testing Submarines

The ingenious Laurenti vessel on the ways ready for launching. It can also be utilised for salvaging sunken submarines.



United States Submarine "Salmon"—D_3—"Running Light" at Full Speed

floated into the dock. Within the cylinder keel ocks are disposed upon which the submarine rests, hile furthermore the latter is held firmly in position the sides and from the top, so that it cannot ssibly move once its position has been assumed. The observers enter the submarine before it sses into the dock, and the underwater fighting ip is sealed as if preparing for a dive. When the ssel has entered the dock the caisson gate is osed tightly to form a joint which is both air and ater-tight. There are two sets of observers rticipating in the test—one party within the bmarine, and the other upon the deck of the dock. mmunication between the two is afforded by eans of telephones, so that those without are pt continually acquainted with what is transpiring thin the submarine during the experiments.

When the vessel has been made fast and the ck closed, water is admitted until the submarine completely covered; in fact the whole space thin the dock surrounding the submarine is oded. Further water is now forced into the ck, this pressure being gradually increased until predetermined limit is attained. Applying the ater under pressure against the hull of the sub- arine in this manner is equivalent to the sub- ergence of the vessel to a corresponding depth the open sea. Thus when the recording instru- ent indicates that a pressure of 30 pounds per

square inch is being exerted upon the hull of the submarine, this is precisely the pressure which the submarine will experience when submerged in the ordinary manner to a depth of 69 feet, and so on. The dock is so designed, and is built of such strong materials, as to be capable of withstanding a pressure greatly in excess of that to which the submarine is exposed during the test, and consequently one far greater than the submerged craft is likely to incur during its subsequent operations when in actual service.

But the determination of the structural strength of the hull of the submarine is merely one factor. There are many other points equally vital which demand decision. For instance: Are the pumps capable of working efficiently and satisfactorily when the submarine is submerged to a depth of 180 feet? Will they overcome the external or back pressure of the water, which at this depth represents 78·3 pounds per square inch? Are the ballast tanks sufficiently strong to withstand the foregoing external water pressure at that depth? And so forth. Under the conventional submergence test these factors cannot be decided owing to lack of observers, for any failure of the pumping system and the expulsion of the water from the ballast tanks would result in disaster for all concerned. With the Laurenti dock, however, such issues may be cleared up effectively and in absolute safety.

hould anything go wrong with the submarine hile under test it is only necessary for the ob- rvers within the vessel to telephone to their omrades outside. The water pressure is relieved mediately, permitting the release of the submarine ithin a few minutes.

In order to enable the work to be carried out with very efficiency and reliability, a multitude of de- ces for recording and other essential purposes e installed. The pumps of the centrifugal type e electrically driven. The water is forced into e dock for the pressure test by the aid of a special eam pump. The dock is self-contained, a com- ete power plant being housed upon the deck, but is not self-propelling. In addition to serving as testing dock it is designed to salvage submarines hen required as narrated in another chapter.

The dock, since it established its utility, has under- ne considerable improvements. Originally it was signed to be used in conjunction with a dry graving ck, but this was a drawback, since the dock could used only where dry-docking facilities were ailable. To extend its sphere of usefulness it as imperative that it should be capable of operat- g anywhere, so long as there was sufficient depth water for floating the submarine. Accordingly e builders adapted the vessel to serve with a bmarine tender or parent ship. One distinct vantage is obvious. Under the ordinary sub-

mergence conditions it is necessary to take the submarine to a point where there is sufficient depth of water, such as the open sea or a deep estuary. By means of the testing dock, however, far more valuable data can be obtained in shallow waters: the necessity to take the submarine out to sea does not arise. In fact the trials may be carried out in the secrecy of the builders' yards.

The introduction of the submergence test, complete compliance with which is imperative before acceptance, has not only been responsible for the creation of an enhanced feeling of confidence upon the part of the crew, but has contributed very materially to the stronger construction of the vessel itself, as well as the efficiency of its mechanism. The builders cannot afford to take risks, since a submarine which is rejected because it fails to comply with official submergence requirements is a complete dead loss. A rejected submarine is fit only for the scrap heap: it has no market whatever. In these circumstances, the builders err on the right side by building their vessels of sufficient strength and fitting them with mechanism sufficiently powerful to meet with the conditions which exist at a depth from 25 to 40 per cent. in excess of the official requirements.

CHAPTER X

THE OPERATION OF THE SUBMARINE

WHILE the ethics of submarine warfare have constituted a favourite theme for animated and academic discussions, the fact that the vessel has been definitely accepted and is being used by the various Powers as a fighting unit rather stultifies further controversy of this character. To-day we are face to face with the incontrovertible fact that the submarine is a deadly offensive weapon, over-rated perhaps, as is the tendency with anything new, but one that has proved its value in a manner exceeding the most sanguine anticipations of those who were in a position to estimate the possibilities of the craft. One may feel disposed to deprecate its system of attack, which certainly resembles that of the assassin lying in wait for his victim, but that hardly affects the general question. The submarine has fully earned the unenviable reputation of being the Assassin of the Sea, and therefore it is interesting to learn something of the tactics which it pursues to accomplish its fell work.

The secret of the submarine's success lies in its power to become invisible, and the capacity to take every advantage of this characteristic. But the

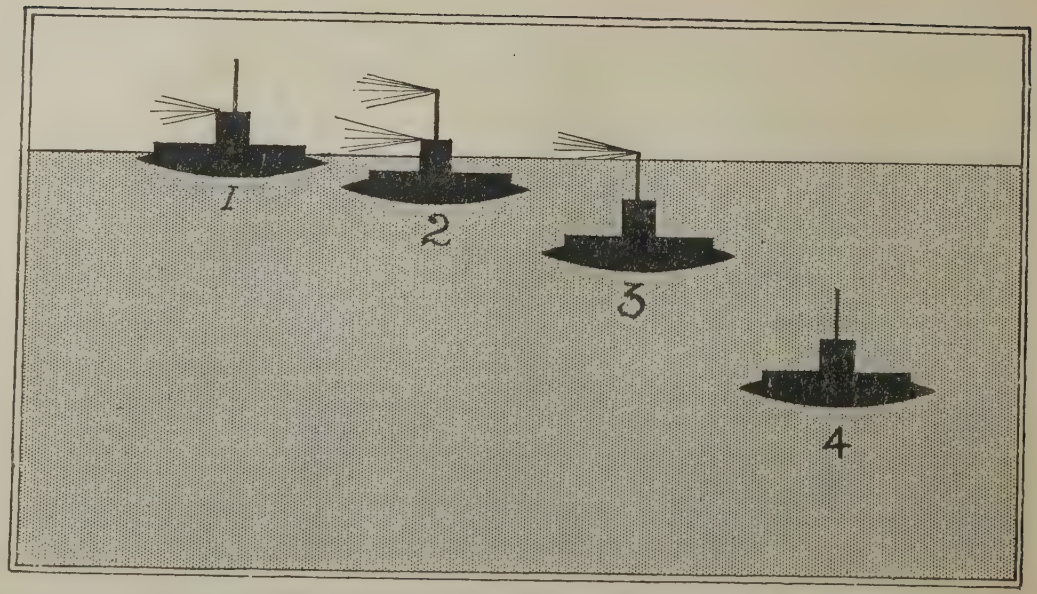


FIG. 3.—THE DISTINCTIVE TRAVELLING CONDITIONS OF THE SUBMARINE.

(1) "Running light" or "cruising": all ballast tanks empty: look-out from bridge, periscope being out of use. (2) "Awash": look-out from bridge or periscope. (3) "Submerged": periscope alone projecting above the water. (4) "Totally submerged": steering by compass.

bmarine does not, as it were, live, move and have r being beneath the waves, as the name might ggest. Her normal position is on the surface, ver of the water only being taken in moments of nger, or when about to launch and to push home attack. Although the underwater fighting ship generally considered to be invulnerable, yet it is enaced constantly by one remorseless enemy ainst which it is virtually powerless. This is the gh-speed destroyer, for which the submarine has profound respect and of which it goes in dire ead.

There are three broadly distinctive conditions der which a submarine may be said to move and operate. The first is the " light " or " cruising " ndition, where she stands as high out of the water is possible. The whole of her ballast tanks are pty. She may be fully rigged, although, in nes of war, the amount of top-hamper is reduced the minimum, because the submarine must ever ready to sink under water at a moment's notice. The second condition is the " awash." In this tance only those water ballast tanks which are pt full when running submerged are in the empty te. This condition may almost be described as secondary phase of " running light," because the ssel is only a little lower in the water. Her deck y be still free, while her bridge may even be rigged. t the fore and aft trimming tanks, as well as one two other compartments, have been charged

with water to such a degree as to maintain the trim of the vessel to ensure that she will submerge instantly and without any further adjustment when the main ballast tanks are opened. The difference between the "light" or "cruising" and the "awash" conditions is so slight as to be beyond distinction by the layman. Consequently, the two terms have become confused and resolved into one, a submarine generally being described as running awash when any part of her conning tower and deck is exposed, or when her cruising bridge is in use and her wireless telegraph aerial is rigged.

The third condition is "submerged," which, as its name implies, represents the stage when the vessel is running completely underwater. In this condition the main ballast and other tanks have been charged with water to such a degree as to leave only a small reserve buoyancy. The vessel is then able to travel at any depth up to the maximum for which her hull has been structurally designed.

Notwithstanding the apparently intricate character of the mechanism of the submarine, the operation of the vessel may be very simply described and readily understood. Only a few minutes are required to pass from the "cruising" to the "submerged" condition, the rapidity of the change depending upon the quantity and character of the top hamper which has to be removed preparatory to submerging. However, the deck hamper is

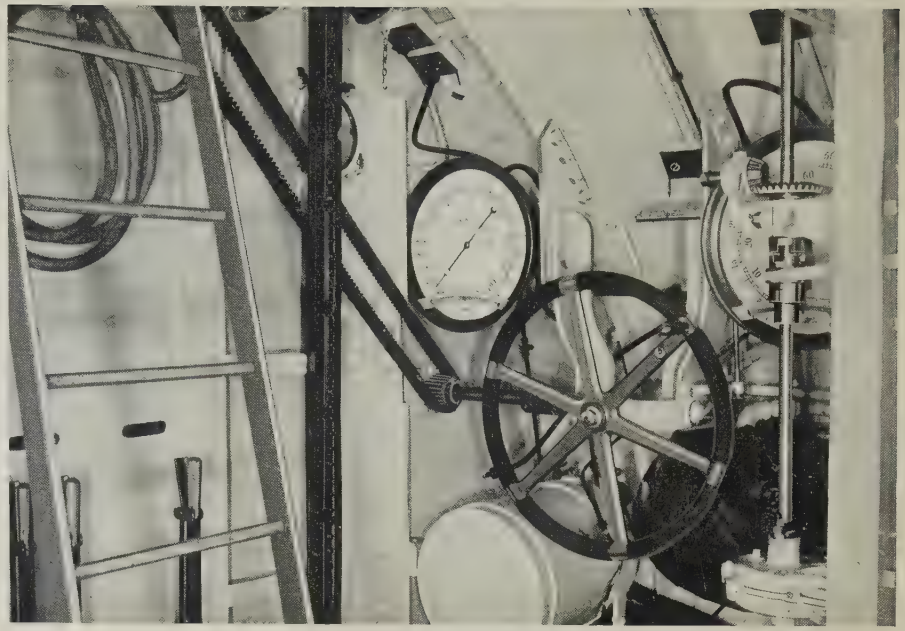
readily removable and is stowed within the vessel. The conning-tower hatch is now closed and made fast and watertight from within the vessel, while any other openings in the hull, such as those to ventilating conduits, are closed and sealed by means of valves controlled by handles.

When all is completely sealed, the water is allowed to pour into one or more of the large ballast tanks in order to destroy the greater part of the vessel's capacity to float: in other words to sink her. Gauges are watched closely as this operation proceeds, so that just the correct volume of water and no more may be admitted. Some water is then allowed to enter the fore and aft tanks in order to bring the boat on a level keel. The tanks in the centre of the boat are now carefully flooded so as to reduce the buoyancy to a few hundred pounds. This last-named operation does not affect the inclination of the submarine to any material degree, as she sinks steadily upon a level keel, but the object is to destroy the vessel's remaining possibilities of floating. As may be supposed, these respective and varied operations are somewhat delicate, but full control over one and all is assured by the different gauges, so that each stage of the operations may be followed with facility and be performed with exactitude. The boat being at rest, the effect of flooding the tanks is to lower her into the water until only the top of the conning tower protrudes above the waves.

Everything is now ready for disappearing under the water. The electric motors are started, and under the propulsion of the screws the boat moves forward. In so doing the resistance offered by the water and bearing upon the deck and water- or hydro-planes, which are horizontal rudders, forces the vessel downwards into the sea, until at last she disappears completely from sight, not even her eye being visible. All steering operations in the vertical plane—that is, variations in the depth of travel—are carried out by the horizontal planes, wherewith the vessel is also kept to the desired depth. Steering in the horizontal plane—that is, to port or starboard—is effected by means of an ordinary vertical rudder at the stern such as is carried by surface vessels.

One might almost say that the manipulation of a submarine when submerged is somewhat similiar to the control of an airship. Both vessels are fitted with two distinctive sets of rudders to facilitate movement in the two planes of the respective mediums.

The man at the wheel has complete control over his vessel. He can satisfy himself instantly that the vessel is running at the desired depth, upon an even or level keel, and to the desired course. A pressure-gauge indicator records the one, and it virtually serves as a compass in the vertical direction. Another device similiar to a spirit-level shows whether or no the vessel is maintaining



DIVING STATION OF THE HOLLAND SUBMARINE
Showing control wheel and gauges or depth indicators.

First stage: Angle of declination $\frac{1}{2}$ degree

Second stage: Declination increased to $1\frac{1}{4}$ degrees

How the Holland Submarine Dives

an even keel. The position of the bead reveals whether the prow is declined or inclined, and, in steering, the task is to keep the bead at the central or zero point by the movement of the horizontal rudders. By means of the system of gauges, with indicators, which immediately face the steering position, and which register with striking precision, the helmsman is never in the slightest doubt.

From the description of the submerging process one might conceive that it occupies considerable time. But this is not so, although it varies appreciably with different types of boats, and is influenced by the extent of the top hamper which is being carried when the boat is running light. Under normal conditions passing from the cruising to the totally submerged state takes about eight minutes, but when the submarine is cruising, cleared for action, she can submerge totally in about 180 seconds. This appears to be a short span of time, but if a high-speed destroyer be in the neighbourhood it is none too brief, because an enemy vessel of this class, making 33 knots, is able to cover 3,347 yards—nearly two miles—within that time.

Occasionally one reads sensational stories of remarkable diving feats which have been accomplished by submarines; how a submarine, surprised, has dipped literally head foremost to seek the sanctuary of the deep. But it is merely a fantastic picture. As a matter of fact a submarine does not dive at all, at least, not in the generally accepted

sense of the term. After the water has been admitted into the tanks and the vessel has been brought to the condition ready for total submergence, she glides down an almost imperceptible declivity to the required depth. Under ordinary conditions the angle of the declination, and likewise inclination when coming to the surface, does not exceed two degrees, but, if the occasion demands, the vessel can dive at an angle of five degrees or more with perfect safety. This is the outstanding feature of the American Holland and of the British submarines, as well as of the latest craft of the German Navy.

When the periscope of the submarine is projecting above the water, the steering of the submarine in the horizontal plane is carried out upon precisely similar lines as if she were travelling upon the surface, bearings and observations being made through the eye of the craft. But when she is totally submerged, dependence in this plane has to be placed exclusively upon the compass. The plight of a submarine when moving underwater is analogous to that of a surface vessel enveloped in a fog. She has to grope her way forward and run practically by dead reckoning. There are no means of determining side drift or the velocity of adverse or favourable currents, the result being that whenever an opportunity occurs the vessel rises to lift its eye just above the water in order to check the course which she has run and to ascertain her exact position,

In reality, a vessel moving under water is comaratively helpless. She has very little idea of vhere she is going beyond the broad path indicated y her compass, and she is entirely ignorant of vhat is happening about her. In many cases this a very serious handicap, and is likely to contribute o disaster. It was this disability which was reponsible for the disaster to the French submarine *endémiaire* during the manœuvres of 1912. The ubmarine was taking part in the mimic attack upon ne battleships in the ill-famed Raz Blanchard near herbourg. The vessel submerged, set her course nderwater and returned to the surface, the comander calculating that upon rising he would be bout 400 yards from his objective and would have eached an ideal point for discharging his projectiles. ut when he peeped above the water he found, to s dismay, that the currents, which run viciously this point, had completely upset his scheme and at he was only 100 yards from the ram of the dmiral's flagship *St. Louis*, which was bearing own upon him. The flagship endeavoured to void her underwater consort by reversing her gines, while the submarine strove to get away y diving. But the battleship had too much way her. A bare twenty seconds of time sufficed carry the battleship forward the intervening o yards. She blundered into the submarine, pped her in twain and sent her to the bottom with e whole of her crew. It was the velocity of the

currents which brought about the stranding and subsequent loss of the British submarines *AE2* and *E16* in the Dardanelles, in the course of an attempt to pierce the Narrows in order to penetrate the Sea of Marmora.

If a submarine be cruising she may be sighted by a battleship from a distance of 10 miles in clear weather, but she offers such an insignificant target that she is immune from gun fire. On the other hand, if the submarine be travelling submerged but with the periscope protruding its full length above the waves, she can pick up the warship at a distance of 5 miles, and yet at the same time be invisible to the large surface vessel. But a submarine cannot attack from such a range. She must push her way forward until she is not more than 2000 yards—about 1¼ miles from her target. Even this is an extreme range at which to carry out an attack with any degree of certainty. Consequently, a distance of 1000 yards is considered to be the maximum by many submarine strategists, and even this distance should be reduced by the submarine as much as possible without imperilling her own safety, in order to be sure that the torpedo shall find its mark. Although the torpedo of to-day appears to be of high speed and a perfect missile, yet it is somewhat erratic, unreliable, and relatively slow in movement when compared with the velocity of a shell fired from a heavy modern naval gun.

When an enemy ship is picked up, the first task is to determine its course and speed in relation to that of the submarine. If the former is travelling away from the submarine and at a speed exceeding that of the latter then the warship is safe, but if she has a turn of speed inferior to that of the submarine then she is doomed. The chase being a stern one, will be long, but unless something unforeseen happens, the submarine must triumph. This fact applies in all instances where the speed of the surface vessel is exceeded by that of the underwater fighting ship irrespective of the course taken. Should the speeds of the two vessels be about equal the battleship has a chance of escape, but the possible zone of safety is comparatively small. On the other hand, if the warship has an overwhelming advantage in speed, such as, for instance, 25 knots against the 12 knots which the submarine may muster underwater, the zone of safety through which the battleship is able to effect her escape is very high. In fact, if a sharp look-out is maintained and the periscope of the submarine be picked up at long range, the battleship, instead of being stalked may turn the tables completely.

But we will suppose that everything is favourable to the submarine, and that the battleship is steaming unconscious of the existence of the assassin. The submarine "spots" the enemy at a range of 5 miles. After determining the course and speed of her victim she submerges and proceeds to draw

in to a range of 1000 yards or so. The submarine must make her way towards her prey underwater, since to approach the latter with periscope exposed is to invite discovery from the long trailing ribbon of white foam or wake caused by the movement of the periscope through the water.

In the underwater run the submarine will probably travel at slow speed, so as to husband her submerged speed resources until the critical moment when the attack has to be driven home. At intervals the submarine rises to thrust her eye warily above the water to take observations. When she has come within 1000 yards and has escaped detection, she enters what may be termed a zone of excessive danger. The commander considers that he may safely run another 200 yards before launching his torpedo, so he takes a final observation, disappears, and then crowding on all power, he makes the last lap of 200 yards at full speed. The missile is launched. Speed is reduced, although the submarine holds on to her course, and all is tranquil for a few seconds. The commander, calculating that the torpedo has run her course, raises his eye to ascertain the result. If he is not satisfied he instantly dives once more, and discharges a second projectile, correcting the aim if necessary. Another peep is taken and a third projectile may be necessary, in which event he sinks again and fires. During this period he has been drawing ever nearer to his prey, and the third

Third stage : Declination angle 2 degrees

Fourth stage : Declination eased to $1\frac{1}{4}$ degrees

How the Holland Submarine Dives

The Dive completed

Running submerged

shot proving effective, he either throws the helm hard over, turns and scurries away, or, should there be no possible danger, he probably sheers and rises to the surface to survey the result of his destructive handiwork.

The discharge of a torpedo appears to be a straightforward operation, but, as a matter of fact, careful calculation is necessary to make sure of a hit. In torpedo firing, the percentage of misses is inordinately high. The range has to be calculated to a nicety so that the projectile may be adjusted, while the vessel which is to be the victim must be accurately discovered in order that the submergence of the missile may be definitely calculated. For instance, whereas a Dreadnought will draw 30 or more feet of water, that is, the depth of the hull below the water-line, a destroyer may draw only 9 feet. Obviously the setting of the depth of submergence for the former will not suit the latter : the torpedo will pass harmlessly under it. As a matter of fact a destroyer is one of the most difficult vessels to put out of action with this projectile owing to the light draught, because it is almost impossible to set a modern high-speed torpedo to such a slight depth adjustment. The missile as a rule will broach to the surface or pursue a wildly erratic course.

Again, the speed of the enemy ship must be accurately estimated. Unless the boat is a large one and the submarine is able to approach so closely

as to take a point-blank aim, the torpedo is not directed at the target, but at the spot the latter will reach by the time the torpedo has run its course, say 1000 yards (Fig. 4). This may be more easily understood by reference to the accompanying dia-

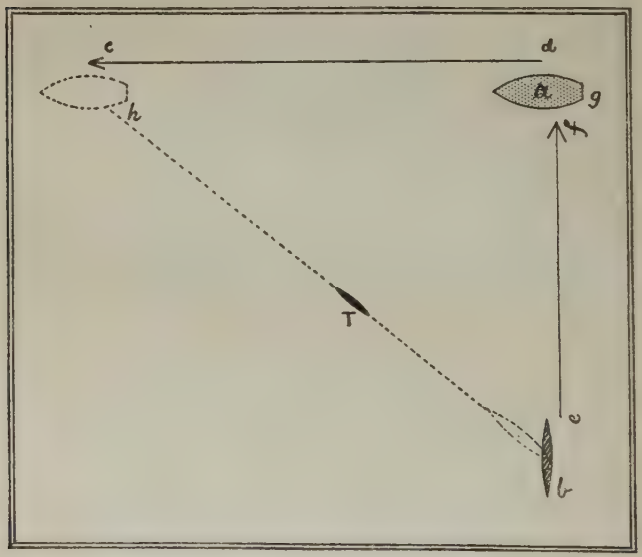


FIG. 4.—A TORPEDO ATTACK BY SUBMARINE.
(For explanation see text.)

gram Fig. 4. The warship *a* is travelling at 23 knots in the direction *cd*, which is at right angles to that of the submarine *b*, which is running the course *ef*. The torpedo T is fired at a range of 1000 yards and travels at a speed of 46 knots—twice the speed of the warship. At this velocity the missile will take thirteen seconds to

ach the target. Meanwhile, the warship, which steaming at 23 knots, has moved from *g*, the osition which she occupied at the instant the rpedo was fired, to *h*, which represents the point here projectile and target will meet, the vessel ving moved forward 500 yards while the missile as in flight.

The firing of a torpedo, even at point-blank range, lls for very skilful handling of the submarine. he tube itself cannot be laid in the manner of a n: the whole vessel, of which the tube is an tegral part, has to be trained.

While the modern submarine is designed to move any level between the surface and 200 to 250 feet low, the normal travelling depth is from 30 60 feet, the submarine descending to the latter pth when called upon to pass under a battleship as to secure ample clearance between the top the periscope and the keel of the surface vessel. e submarine is quick to answer the operation of ballast tanks, the latest vessels being able to e from a depth of 30 feet to the surface and to urn to the former depth in about forty seconds. What are the sensations when travelling upon submarine? When the vessel is moving awash l even when only a few feet below the surface is subjected to the same movements as a surface ft. But at the 30-feet or deeper level unless water be shallow there is no sense of movement. deep water, at a depth of 50 feet, the sensation

is very similar to that of a balloon when aloft The vessel is well beyond the surface disturbanc of the water, and therefore does not roll or pitch When moving at high speed there may be som vibration, but nothing else. If the boat is stationary and all is quiet and still the silence is peculiar an eerie. When she is running submerged there i only the low musical hum of the motors to be heard If the boat be operating in shallow water a curiou bumping sensation may be experienced, which i due to the ground swell.

In order to return to the cruising condition, process the reverse of that necessary to submerg the vessel is followed, and the various operation are just as easily and as readily performed. Th buoyancy of the boat is partially restored by eject ing some of the water from the ballast tanks b the aid of the pumps, the horizontal rudders ar set, and the vessel follows a steady upward slantin course. When the conning tower emerges fro the water, and an even keel is regained, the electri motors are stopped, the hatch is opened, and th oil motors are set going. If all is clear, the contr of the vessel is transformed from the conning towe to the outside navigating bridge and the vesse merrily resumes cruising.

CHAPTER XI

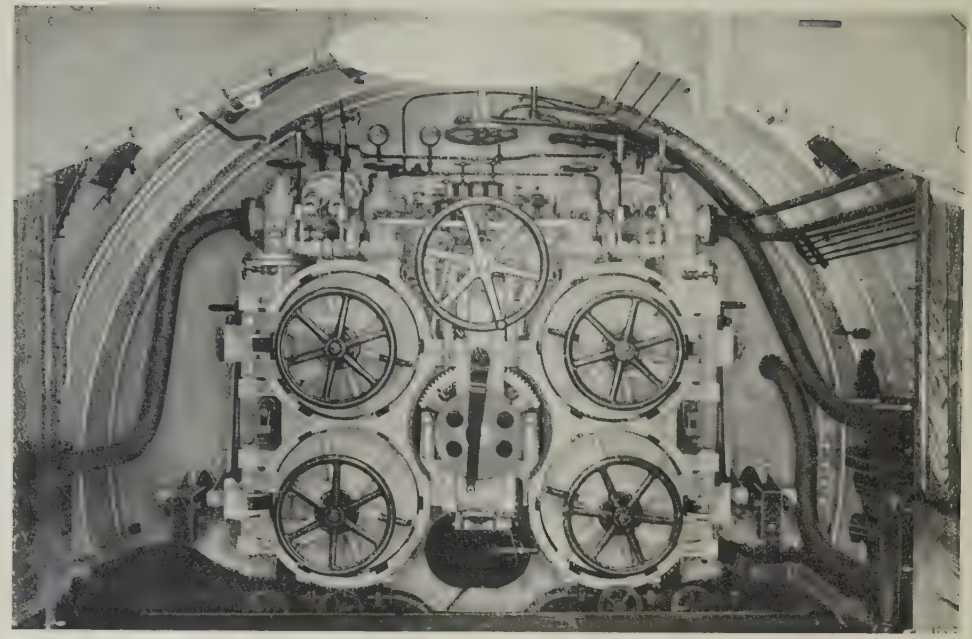
THE TORPEDO, THE SUBMARINE'S DEADLY ARMAMENT

THE submarine and the torpedo have ever been inseparably associated. When Fulton and his contemporaries delved into the problem of underwater navigation there was but one governing purpose—to rend the hull of an enemy ship so fearfully, by the aid of a missile containing explosive, as to cause the vessel to founder. It constituted the sole means of accomplishing the desired end by underwater tactics.

But even as the submarine of to-day differs so widely from that produced a century or more ago, so has the torpedo been improved beyond recognition. In those early days it was a "dead" missile. It had to be attached to its target and then detonated. Nowadays it travels under its own power, at a high velocity, and accomplishes its purpose automatically. It is essentially a self-contained, mechanically-propelled projectile, and for this reason is generically described as the automobile torpedo, to distinguish it from other similar missiles which are deficient in propelling mechanism, but which coincide with the term torpedo.

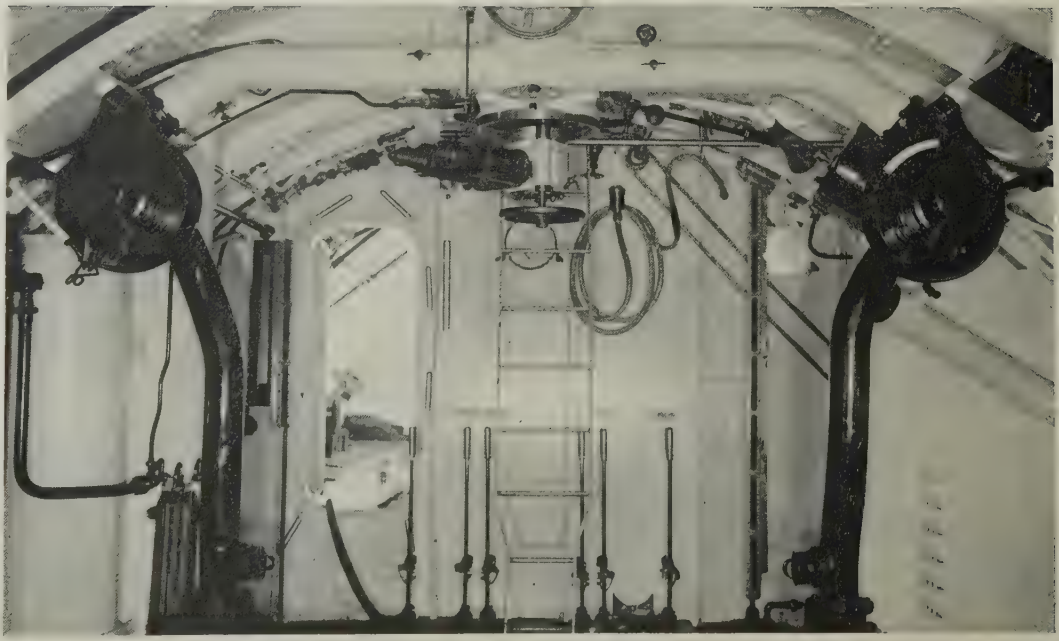
The most deadly arm of the modern submarine owes its creation to a British engineer, Mr. Whitehead, who had established his works at Fiume in Austria. One day there came to him an inventor, Captain Lupius, of the Austro-Hungarian Navy, with an idea and designs for a new projectile. The British engineer listened to his visitor's proposals and scrutinised his rough plans. He speedily realised that the inventive officer had certainly contrived a new vehicle of destruction, and also appreciated the fact that in its crude state it was unworkable. But the idea was an adequate foundation for the prosecution of further experiment, and the British engineer threw his whole energies into his task. It proved a heartbreaking quest, but at last he evolved a torpedo which was self-propelling and automatic in detonation. It had a speed of some 6 knots, which it was able to sustain for a few minutes, while it carried a charge of dynamite which was fired upon impact. The trials with this missile were not precisely stimulating, because often the projectile failed to maintain its course and to strike its objective. However, these defects were capable of being remedied. It was merely a question of time, perseverance and untiring patience overcoming a defect as it became manifest, and effecting improvement upon improvement.

In these early days some of the experiments were not without their humorous aspect. Sometimes,



THE BUSINESS END OF A HOLLAND SUBMARINE

A nest of four bow torpedo tubes showing breech blocks. In the latest vessels a second installation is carried at the stern.



THE BRAIN OF THE HOLLAND SUBMARINE

Commanding officer's station, showing controls. Near the roof may be seen the eye-pieces of the periscope.

when the torpedo was released, it evinced a distinct desire to run away from instead of towards the objective. At others it would describe a circular course and would continue cutting circles until it had tired itself out; that is until the driving force became expended. On further occasions it would perform the most remarkable geometrical evolutions in the water. Such eccentric behaviour was certainly tantalising, but step by step these erratic tendencies were eliminated and the projectile was induced to strike and to make a bee-line for its target. Even to-day the missile, wonderful though it is in its construction and precise in its behaviour, will occasionally prove erratic. Shortly before the war a submarine was carrying out evolutions in torpedo attacks and a missile which was fired followed a circular course and finally came to rest within 20 feet of the point from which it was discharged.

Despite his trials and galling intermittent failures, Mr. Whitehead at last so perfected his machine that in 1876 he produced a torpedo carrying 26 pounds of gun-cotton and capable of travelling at a speed of 18 knots. Run after run was made and checked, and it was found that invariably the missile followed an absolutely straight course and kept to the path desired with unerring accuracy. But the torpedo which accomplished such results and which became accepted as a proved arm bore

little, if any, resemblance to the idea originally laid before the engineer by the naval officer. Accordingly it became known as the Whitehead torpedo, by which it is known throughout the world to-day. It is universally used by the Powers, although in Germany the projectile of this nature which is used, although fundamentally the same, is known as the " Blackhead."

The torpedo is probably the most wonderful piece of destructive mechanism yet produced. Though simple in its design and operation, it is always invested with awe and mystery by the average individual. In its external appearance it very closely resembles a fish without fins, perhaps more particularly the shark. There is a blunt, rounded head, a smooth, gradually tapering body, and tail composed of the propellers and rudders. The skin is made of tough steel, about half-an-inch in thickness, and finely polished upon the outside to facilitate movement through the water.

The torpedo may be said to comprise two distinctive parts. The head, known as the " warhead," may be described as the business end, seeing that it carries the explosive charge and the means of achieving its detonation. In the latest projectiles, which measure 21 inches in diameter, the warhead is packed with 330 pounds of gun-cotton or trinitrotoluene, the latter being the explosive preferred by the Germans. A striker, called

the "pistol," extends right through the mass of explosive or "head." This is a steel rod, the inner end of which is pointed, while the outer end projects a few inches beyond the nose of the warhead and is fitted with a thread on which is wound a butterfly nut and what are known as the "whiskers." In the latest types the nose is further provided with cutters to enable the torpedo to cut its way through the protective steel nets which a warship throws out as a measure of protection when she is at anchor. Within the warhead and immediately behind the explosive charge is the detonator, against which the pointed end of the pistol comes in contact when the objective is hit.

The body proper of the torpedo carries all the mechanism for propelling and steering the projectile after it has been launched, and is subdivided into a series of compartments each of which fulfils a defined duty. Starting from the fore end of the body, these chambers comprise respectively the compressed air reservoir, immersion or balance chamber, engine space, and buoyancy chamber.

The tiny engine is driven by compressed air which is compressed to a high degree, and it rotates the propellers whereby the projectile is carried through the water. Formerly the compressed air was used in the cold condition until a means was discovered and perfected of enabling a charge of this fuel to perform considerably more

than its normal duty. Immediately before passing to the engine the air is heated, or rather superheated, an equable and steady temperature being maintained throughout the projectile's run. The perfection of this device increased the deadliness of the torpedo to a remarkable degree, since it was found possible to increase the projectile's radius of action or flight to a remarkable extent without increasing the compressed air charge. In other words, 100 cubic feet of air compressed to, say, ten atmospheres can be made to perform far greater work when heated before passing to the engine than if used in the cold condition.

The immersion or balance chamber provides the means of maintaining the depth at which the torpedo shall travel through the water after being launched. It is a means of correcting any deviation in the vertical plane and is remarkably sensitive and quick in its action. In the engine chamber there is also the device for keeping the projectile to its designed path during its travel. This is achieved by means of a gyroscope which corrects any tendency of the projectile to deviate in the horizontal plane, *i. e.* right or left of its designed path. The buoyancy chamber, which is placed aft of the engine chamber, is virtually a vacuum and, as its name implies, its object is to give the requisite degree of buoyancy to the missile. Without this chamber the torpedo would sink. At the extreme rear, and outside

the body, are the propellers, of which there are generally two, each of three blades, mounted one behind the other upon a single shaft, and the rudders.

In the United States Navy another type of torpedo in addition to the Whitehead is employed. This is known as the Bliss-Leavitt turbine torpedo, which is claimed to be superior to the older and more widely known projectile. This automobile torpedo follows its prototype in the general particulars and disposition of the mechanism and chambers, the most important deviation from the Whitehead model being the use of a small turbine as the driving engine. This little turbine, of the compound Curtiss type, comprises a central row of fixed blades and two wheels, one slightly smaller than the other. This mechanism runs at 10,000 revolutions per minute, but is reduced through gearing to 900 revolutions for driving the propellers, which represent about 160 horse-power. The compressed-air chamber is charged with air to an initial pressure of 2,225 pounds per square inch. The air-superheating system is also incorporated, there being a small burner which is fed with alcohol during the flight of the projectile. The moment the missile is fired this burner is ignited automatically and burns continuously during the travel of the projectile.

The correct depth of submergence is maintained

by the mechanism in the immersion or balance chamber. In this compartment there is a vertical diaphragm, upon one side of which water pressure is brought to act, while upon the opposite side are a series of coiled springs bearing against the diaphragm. The tension of these springs is so adjusted that when the torpedo is travelling at the desired depth the pressure of the springs is exactly equal to that of the water upon the diaphragm. Should the torpedo descend to a depth exceeding that for which it has been set, then the water pressure becomes greater than that of the springs, and *vice versa* if the torpedo should deviate in its vertical plane in the opposite direction. The flow of the water to and from the chamber according to the movement of the diaphragm is free, there being adequate perforations in the skin of the torpedo for this purpose. In moving to and fro in its chamber the vertical diaphragm actuates a pair of horizontal rudders which correct any deviation in the vertical plane and thus keep the weapon moving at the requisite depth through the water.

In the Bliss-Leavitt torpedo the gyroscope is also driven by a small turbine. This is of the reaction type which at full speed makes 18,000 revolutions per minute. This weapon is now extensively adopted in the United States Navy, the authorities having been completely satisfied with the results of the experiments therewith. It is

made in two sizes, 18 and 21 inches respectively, and has a speed of 36 knots at 1000 yards' range, while its maximum range is 4000 yards.

The torpedo is launched from a tube, the discharge being effected by means of compressed air instead of by means of an explosive, as in the case of a shell fired from a gun. Before the torpedo is slipped into its tube a pin which is driven at right angles through the pistol outside the nose is withdrawn. This is the safety pin, and, in fact, until it is withdrawn the torpedo cannot be fired. This serves to hold the striker, which passes through the warhead, from hitting the detonator, thus preventing a premature explosion. The butterfly nut, which is screwed on to the outer end of the pistol, as already mentioned, also serves as a safety device. It is not held upon the pistol by a locknut, but is free to unscrew. When the torpedo is fired, and directly the projectile strikes the water, the forward movement of the missile through the water causes this butterfly nut to unscrew and finally to drop off. This occurs a considerable distance from the ship, so that should the torpedo foul an obstacle, such as floating wreckage, before the butterfly nut has come adrift, the torpedo cannot explode. But for this precautionary device an explosion within a few feet of the vessel from which the projectile has been fired might occur. When the butterfly nut drops clears of the pistol the torpedo

becomes exceedingly dangerous. Directly it strikes an object such as a ship's hull the pistol is driven backwards by the force of the impact, causing its inner pointed end to strike against the primer or detonator with considerable force, thereby bringing about the firing of the explosive charge in the war-head. It is not necessary for the missile to hit its target fairly and squarely. If a glancing blow be struck the charge is fired because the whiskers ensure the pistol being driven back irrespective of the angle of incidence.

It will be seen that the torpedo belongs to the impact or concussion class of projectiles. That is to say, it will not explode unless the nose hits something. Under these circumstances one would think that the impact against the protective net of a warship would be adequate to fire the charge, but this is not so. Upon several occasions a live torpedo has been recovered caught in the net. In the latest types of this missile, however, the net cutters with which the nose is fitted enable the torpedo to hack its way through this obstacle without turning from its path or appreciably retarding its velocity. The British pre-dreadnought *Triumph* was sunk in this manner, although her nets were out, during the operations in the Dardanelles. Such little faith is placed in the protective qualities of the torpedo net to-day that the latest British superdreadnoughts are without them. The only

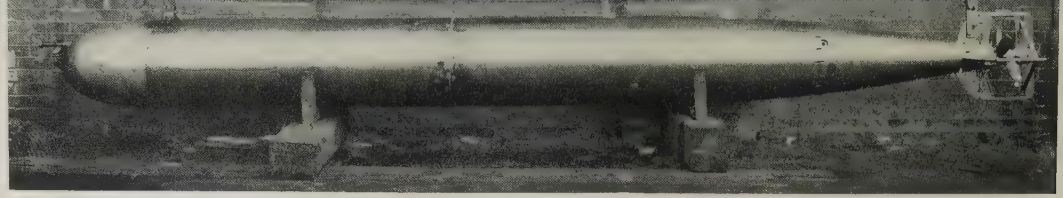
perfect protection against the torpedo is to keep a keen look-out and to have the vessel always on the move. The path of a torpedo can always be descried in the form of a white trail through the water—the fatal streak—and it is therefore up to the commander of the attacked vessel to have sufficient way upon his craft to enable it to be manœuvred readily and so allow the projectile to pass him.

Although torpedoes are built with warheads carrying 330 pounds of gun-cotton, they are not used very extensively in connection with submarine operations. Moreover the 18-inch weapon is considered generally to be sufficiently effective for this work. The warhead charge, in connection with submarine torpedoes, as a rule varies from 100 to 200 pounds, this weight having been deemed adequate for the purpose. One might think that as the weight of the explosive charge was increased so the destructive effect wrought thereby would be proportionately extended. But this is not so. Instead of a torpedo carrying 600 pounds of explosive wreaking three times as much effective damage as one carrying 200 pounds, the additional 400 pounds will only increase the extent of the damage by about 50 per cent. This gain is out of all proportion to the extra quantity of explosive carried, which, in turn, influences the projectile as a whole, not only from the point of view of

aggregate weight, but in connection with its mechanism and other features.

At the same time, however, if the ratio of damage inflicted could be raised it would be worth while to load the projectile with 600 pounds of explosive, since, when pitted against the latest creations of the naval architect's handiwork, there would be a greater possibility of accomplishing the desired destruction or effective crippling of the vessel. In the Whitehead and kindred missiles the charge is exploded, as already described, by impact, so that the disruptive effect takes place against the skin of the vessel. Considerable damage may thereby be wrought, but it does not necessarily mean that the ship is doomed to founder. This fact was conclusively established during the Russo-Japanese war, when ships struck by torpedoes were able to proceed under their own steam either to port or to some convenient point to effect repairs. It may also be mentioned that Messrs. Vickers, Limited, the well-known British armament manufacturers and warship builders, when they built a vessel for one of the Powers, guaranteed that, in the event of a torpedo blowing in 50 feet of the ship's side amidships, she would not only keep afloat, but would right herself from the list produced to ride on an even keel, though she would necessarily assume a greater draught.

In these circumstances, it is obvious that if the



Davis Automobile Torpedo Projectile ready for Firing

Davis Automobile Torpedo Projectile after a Test

The smaller tube projecting from the body of the missile is the gun tube which was not destroyed. In front and at side are the recovered fragments of the warhead.

[*Cribb*

THE "FATAL WHITE STREAK"

The path of the torpedo as revealed upon the surface of the water.

TESTING THE DAVIS AUTOMOBILE PROJECTILE TORPEDO

The column of smoke and water thrown into the air at the moment the missile struck the target.

detonation of the explosive charge could be induced to take place at a point within the vessel, then more widespread havoc would be wrought and the safety of the ship probably imperilled. The force of the explosion would be expended on all sides and might possibly blow out a great length of the ship's bottom, or so start the plating as to produce a heavy inrush of water, which, owing to the pumps having been put out of action, would jeopardise the vessel very seriously. This was the problem to which Lieutenant Cleland Davis, of the United States Navy, devoted his energies, the outcome of which is the Davis-Whitehead projectile torpedo.

The deviation from the Whitehead model, so far as this weapon is concerned, affects only the warhead, and even this difference is not apparent from the exterior. The principle of this weapon may be gathered from the illustration facing page 140. From the fore-end of the torpedo body, and rigidly held in the vertical wall of the compressed air reservoir, extends a tube which is in reality a gun-barrel. This gun is loaded with a projectile carrying 250 pounds of gun-cotton or "T.N.T." and is equipped with a fuse. Although the walls of this gun-tube are less than one inch in thickness, while its total weight is only 350 pounds, it is exceedingly strong, being made of Vanadium steel to withstand a pressure of approximately 110 tons per square inch. As the gun is intended

to be fired only once it can be loaded with a charge which is almost sufficient to destroy the barrel itself. It is the use of Vanadium steel which has permitted the employment of so light a tube, with apparently ridiculously thin walls, and the mounting of a gun with a torpedo which complies with all requirements of balance while keeping within the prescribed limits of weight. Smokeless powder is employed for firing the projectile at the critical moment. In front of the gun comes the nose with the usual fittings, including the pistol and the butterfly nut.

When this torpedo strikes the hull of the enemy vessel the pistol fires the charge of smokeless powder in the gun, which propels the shell, carrying the high explosive forward at a velocity of 1000 feet per second, and driving it into the interior of the ship. By means of a short time-fuse, which is ignited at the moment the gun is fired, and which may be adjusted within certain limits, the explosion of the shell can be made to take place 10 yards, 20 yards or any other desired distance from the hull, *i. e.* within the ship. If no fuse be employed, the projectile will pass clean through the ship and emerge from the opposite side. Naturally the detonation of 250 pounds of high explosive in the engine or boiler rooms, or some other vital part of a vessel, is certain to cause widespread devastation, and as the effects of the explosion would be felt

upon all sides there is the likelihood of bulkheads and other defensive works within the vessel either being destroyed or impaired, thereby contributing to the flooding of the interior.

The possibilities of this devastating weapon were revealed very conclusively in an interesting test (Fig. 5). A cylindrical caisson (*a*) was placed in the water off Fort Strong, Massachusetts. Within this caisson were placed four separate steel bulkheads, each about half-an-inch in thickness. The target was so built as to represent the interior of a warship below the waterline. The torpedo (*b*) was fired from a barge (*c*) anchored 360 feet away. From barge to target a trolley wire was stretched from which the torpedo was slung to ensure accuracy of aim for the experiment. When the torpedo struck the caisson and the internal gun was fired the projectile (*f*) of the latter crashed through the front wall, through the four bulkheads, and emerged from the opposite wall of the caisson to land finally in the mud 175 feet beyond. The fuse for firing the shell was omitted purposely, the express object being to ascertain the penetrative effect of the projectile and the efficiency of the gun. But considerable damage was inflicted upon the front wall of the caisson at the point of the torpedo's impact, a huge hole being torn by the gases produced by the firing of the propelling charge in the gun. As for the torpedo itself (*h*), it was driven backwards for a

distance of 40 feet by the explosion of the gun at the point of impact, while the cylindrical portion of the torpedo, which had enclosed the gun, and which was torn away from the torpedo body, was driven 25 feet backwards (*k*). This demonstration was eminently successful, since it revealed the penetrative effect of the projectile and gave a very conclusive impression as to what would occur if the torpedo struck the side of a ship. It must be remembered that a torpedo strikes a warship at its most vulnerable point—below the waterline and beneath the line of armour belting.

Concurrently with the developments in the design and construction of the torpedo, its radius of action has been extended very appreciably. In 1907 the maximum range of the 18-inch torpedo, which was the largest used in the British Navy, was only 4000 yards, while the explosive charge was 205 pounds. The maximum speed was 33 knots at a range of 1000 yards, declining to 19 knots for the maximum range. The United States Navy, having adopted the Bliss-Leavitt torpedo, had a similar maximum range, but both the explosive charge and speeds were higher, the 21-inch weapon carrying 300 pounds of explosive and travelling at 36 knots for 1000 yards and at 27 knots for 4000 yards. The French navy carried 18-inch torpedoes, but the maximum charge was only 198 pounds, while the projectiles were usually

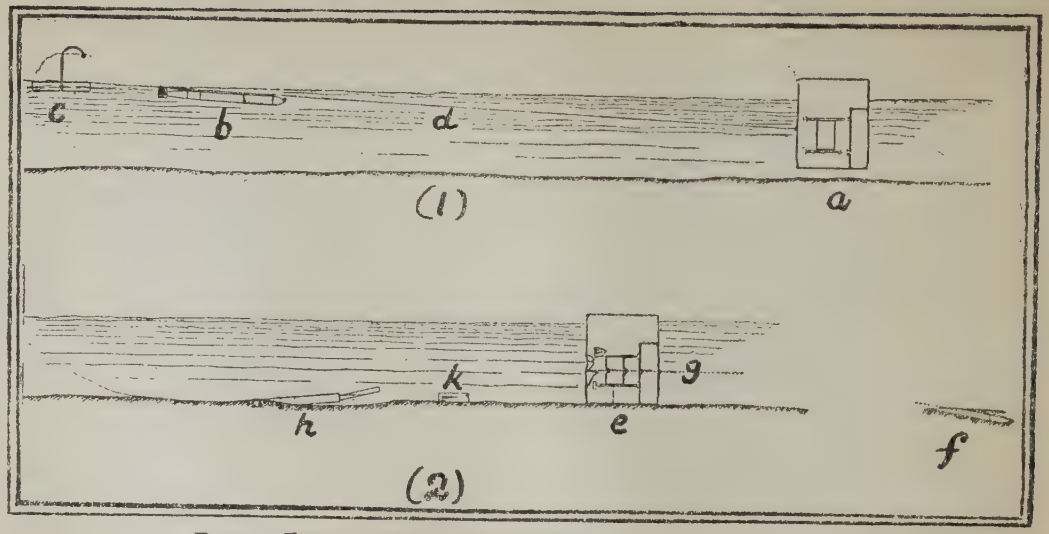


FIG. 5.—TESTING THE DAVIS-WHITEHEAD PROJECTILE TORPEDO.

(1) *a*, target; *b*, torpedo; *c*, barge from which torpedo was fired; *d*, course of torpedo. (2) *e*, target after being struck; *f*, projectile; *g*, line of flight of projectile; *h*, body of torpedo driven backwards; *k*, portion of torpedo enclosing gun driven 25 feet backwards.

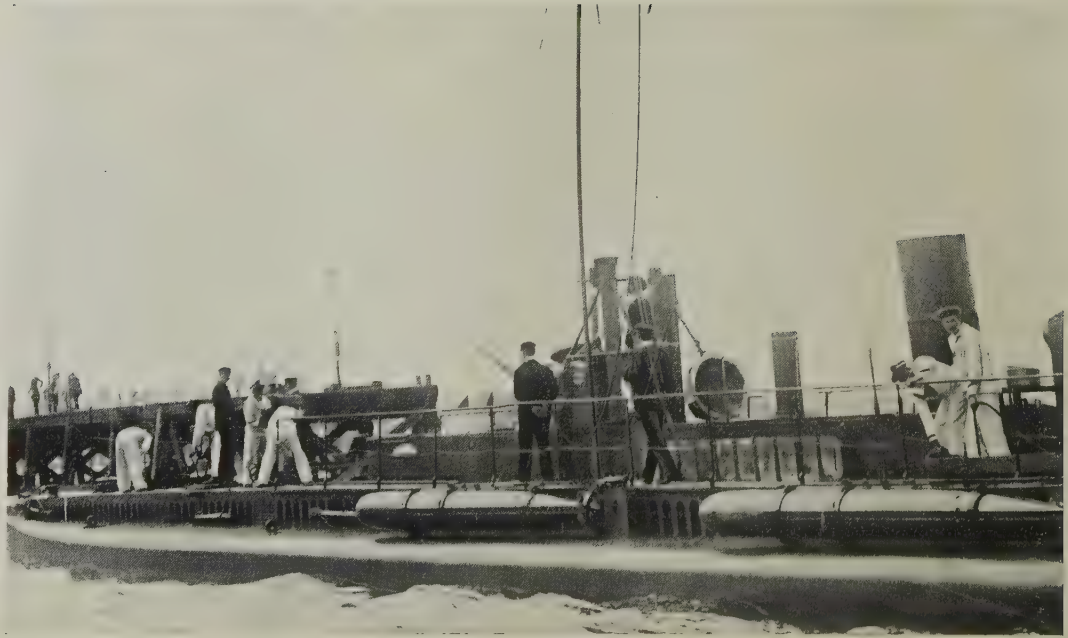
set for a maximum range of about 3000 yards. The German torpedo was even less efficient, for, though the charge was 246 pounds, the maximum range was only about 2,500 yards, while the maximum speed was 30 knots. During the past eight years the torpedo has undergone tremendous development, especially in Great Britain, which, after its adoption of this projectile, has ever remained in the van concerning improvements of this arm.

The present 21-inch Whitehead, carrying a bursting charge of about 330 pounds, has a maximum range of 11,000 yards—6¼ miles—at which range it has a speed of 30 knots, while at 7000 yards range it travels at 45 knots. In the United States there has been no progress, the torpedoes of that country being outranged and outpaced by the British missiles. Germany, however, has overhauled the whole of her torpedo equipment, the latest projectiles comparing favourably in all points with those of the British Navy, since the 22-inch model carries a warhead containing 300 pounds of "T.N.T.," with a maximum range of about 8000 yards, at which the speed is about 30 knots. Since the outbreak of the war the French naval authorities have devoted more attention to this projectile, and their models now compare favourably with those of Germany. Great improvements have been effected by their leading armament manufacturers, who have evolved a distinctive model, and who,

The hole driven through the walls of the caisson and bulkheads by the gun

The huge rent torn in the front wall of the caisson by the gases of the explosion

TEST OF THE DAVIS AUTOMOBILE PROJECTILE TORPEDO



[*Cribb*

A French Submersible showing Deck Torpedoes

from the special facilities which they possess, have been able to complete many important improvements. But the fact is generally conceded that Great Britain, in regard to torpedoes, as with other questions affecting naval affairs, possesses a great advantage over her rivals, a result due, in the main, to the enterprise and initiative of our armament manufacturers, who have been successful in their efforts to improve the deadliness of this formidable weapon by the perfection of many details, and by the incorporation of new and at present undisclosed features.

The fact that the torpedo still remains the main offensive armament of the submarine, developments in light guns notwithstanding, is strikingly revealed by a comparative examination of the modern underwater fighting craft and those of fifteen years, and even of seven years ago. The five British Hollands built in the years 1901–3 carried only a single torpedo tube, placed in the bow. The *A1* was the first to mount two tubes, likewise in the bow, and this remained the practice until 1907, when the *D1* appeared carrying three tubes. In the E class the number was increased to four, but in the latest vessels now being commissioned and under construction the number has been increased.

The American submarines, in common with the British, since they were likewise Hollands in the first instance, carried only one tube, but the latest

craft are mounting eight or more, including the ingenius system of launching the projectiles normally carried upon the deck from their outside cradles by means of apparatus within the boat. France, in the very earliest days, realised that the submarine would have to depend upon the torpedo, and consequently established a minimum of four tubes, although in 1905 appeared the two vessels *Q39* and *Q60* mounting seven torpedo-launching devices. To-day the standard of eight is accepted, including both bow and astern submerged tubes and external launching apparatus similar to that in use in the United States Navy. The first German submarine launched in 1905 carried a single bow tube, but as this was purely an experimental vessel it can scarcely be considered worthy of notice. The German submarine construction programme dates from 1906, when five boats were authorised, in which two tubes were placed in the bow. The installation of a stern tube was recorded in the *U8*, while the number was increased to four—two bow and two stern respectively—in *U17*, built in 1912. The number underwent steady and persistent increase until the latest vessels mount six and eight tubes, disposed in groups of three and four both at the bow and the stern.

The German Admiralty succeeded in springing one notable surprise upon the world. The terrific

character of the explosions produced by a torpedo fired from a German submarine excited considerable comment. What was the cause? At first this result was attributed to the use of a more powerful explosive than that generally employed with such projectiles, and forthwith "T.N.T." was stated to be responsible for this effect. But subsequent study ultimately revealed another and more influential reason. The German Admiralty had introduced a new and more powerful torpedo especially for use with submarines. The outstanding characteristics are the high speed of the missile, short radius of action, and, above all, the enormous weight of the explosive charge. The latter is no less than 420 pounds and, as surmised, is trinitrotoluene. The missile has a speed of about 40 knots at a radius of 1,200 yards.

What developments in this direction the future will bring forth it is difficult to say. The number of tubes is largely dependent upon the magazine capacity of the vessel. The ideal submarine of the moment is described as one carrying eight tubes either of the general fixed internal type or a combination of the conventional type and the external apparatus carried upon the deck of the vessel. But the submarine is being developed so rapidly that the whole policy of torpedo equipment may possibly undergo considerable modification.

CHAPTER XII

GUN-PROTECTED SUBMARINES

WHILE the torpedo constitutes the first and foremost weapon of offence with which the submarine is equipped, it serves nevertheless to restrict the latter's range of utility. This disadvantage was more pronounced with the earlier types of boats than it is to-day, because the modern ocean-going submarine is able to carry from fourteen to twenty of these projectiles. When setting out from port, the tubes are loaded ready for immediate action, a further appreciable supply being carried in the magazine. But when one recalls the enormous radius of action of the modern assassin of the sea, the quantity of ammunition carried is out of all proportion to the volume of useful work which may perhaps be possible of accomplishment during a three months' cruise upon the high seas.

The commander of the vessel is forced to exercise considerable restraint. He must have the capacity to judge whether an enemy craft, which he overhauls, is worth a torpedo, while he has to take unerring aim to make sure that the £1000—$5000—or more representing the value of the torpedo is expended to distinct advantage. Although the

torpedo has been brought to a high standard of perfection, its serviceability is overrated very considerably. One hears about the hits which have taken effect, but not a word is said about the misses. Consequently it is difficult to determine whether the torpedo really is so formidable as is generally supposed. In order to produce a striking favourable percentage the submarine is compelled to incur grave risks and to approach its quarry very closely.

The temptation to let fly at all and sundry is very great to subdue. It is not a simple matter to determine whether an enemy vessel which has been spotted by the periscope is, or is not, worth sending to the bottom. Obviously if a submarine, capable of covering a radius of 5000 to 8000 miles, and carrying say twenty torpedoes, sets out and falls in with a number of apparent non-combatant small craft 500 miles out, at which it discharges all its torpedoes, compelling a return to port for a fresh supply of ammunition, then the very purpose for which the ocean-going submarine was designed has been defeated. The question immediately arises whether the " bag " was value for the ammunition expended.

This great disadvantage was recognised by the British Admiralty nearly ten years ago. The value of the submarine in holding up commerce was appreciated, but the point as to whether the submarine, as it then was known and used, was adapted to this duty was a matter of discussion. It was

argued that the sinking of an empty trawler by torpedo would be a poor haul for a missile which might have been employed to greater advantage. Again, it was quite possible that the enemy vessel would refuse to stop, in which event two or three projectiles might have to be discharged before the fatal hit was recorded. In other words, the torpedo was a poor projectile with which to hold up a ship.

Under these circumstances the question arose whether the value of the submarine as a fighting vessel might not be distinctly enhanced by equipping it with gun power essentially for holding-up purposes. The experiment was made with a submarine of the D class. But the arming of a submarine with a gun of adequate calibre for the duty was by no means a new idea. Two quick-firers were mounted upon the submarines which Nordenfeldt supplied to the Turkish Government way back in the 'seventies of the last century, while the first Holland submarine acquired by the United States Navy carried a dynamite gun, which proved a failure and was dismantled.

A special type of 12-pounder quick-firer, together with a distinctive system of installation and housing upon the deck of the underwater fighting ship, was evolved. One great question which had to be decided effectively was the stowage of the weapon. Obviously it could not be mounted in the usual manner upon the deck of the boat, since its mechanism would be exposed to the corrosive

action of the water, while, worse still, it would increase resistance in underwater travelling and so would reduce the submerged speed of the boat.

An experiment was made. In the deck of the vessel a small well was provided, fitted with hinged flaps resembling a trap-door. In this well the gun was installed upon a special mounting operated by power so as to enable the gun and mounting to be raised or lowered with ease and celerity. With the housing of the gun the trap-doors are closed and bolted, so that a flush deck is presented. By permitting the rims of the flaps when closed to rest upon a cushion of india-rubber, it was found possible to ensure a watertight compartment for the stowage of the weapon.

Submarine 74 was the first British underwater fighting vessel to be fitted with a gun of decisive destructive effect, and, the tests therewith proving completely successful, it was decided to equip subsequent submarines with this additional means of offence. A new line of development was created as a result of this move which is being continued to this day. The fact that this new arm could be rendered still more formidable by such an addition was instantly realised. By this means the submarine was converted into an ideal craft for preying upon unarmed merchant ships; no longer need torpedoes be expended unnecessarily or blindly.

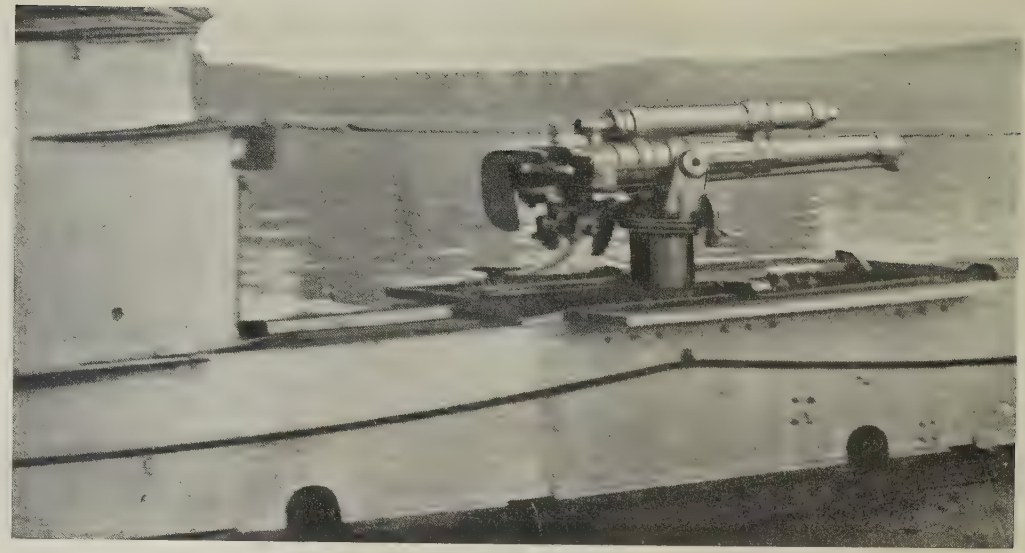
The outcome has been the conversion of the latest types of submarines into exceedingly deadly craft.

The calibre of the guns for the British submarines has been increased, since the science of submarine artillery in this country has risen to the occasion to a remarkable degree.

Once Great Britain had indicated the future lines of development in connection with submarines, other nations embraced the idea, and, as may be expected, Germany was numbered among the copyists. But the Germans accepted the situation somewhat tardily, as they did the submarine itself, with the result that they still have considerable leeway to make up, though much has been heard and said about the work accomplished by the Teuton submarines with their gun-fire.

The Germans accepted the broad lines of British effort, and, as might be expected, it was the Essen armament firm of Krupp which played the most prominent part in this task. In 1907 they produced the first submarine gun, which, in its broad essentials, is really an adaptation to submarine conditions of the Krupp anti-aircraft weapon. The gun is of 7·5 calibre—3 inches—and weighs 1,892 pounds —nearly 17 hundredweights. It is housed, when out of action, in a small compartment upon the deck of the vessel, as previously described.

The system of mounting, however, differs radically from that adopted in Great Britain. Whereas the latter enables the gun to be raised and lowered vertically, the German arm swings upon an axle, turning completely over in the course of its move-



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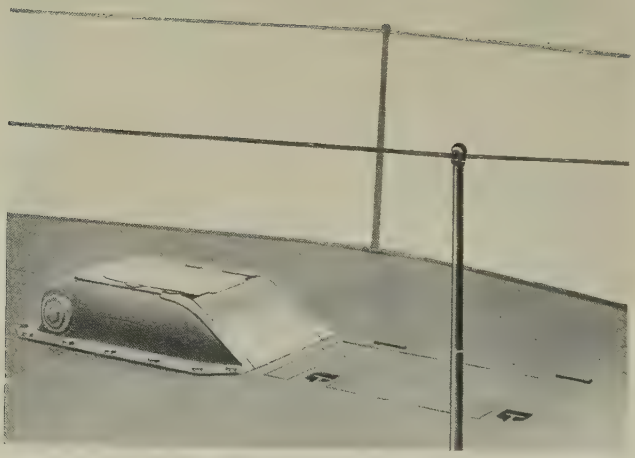
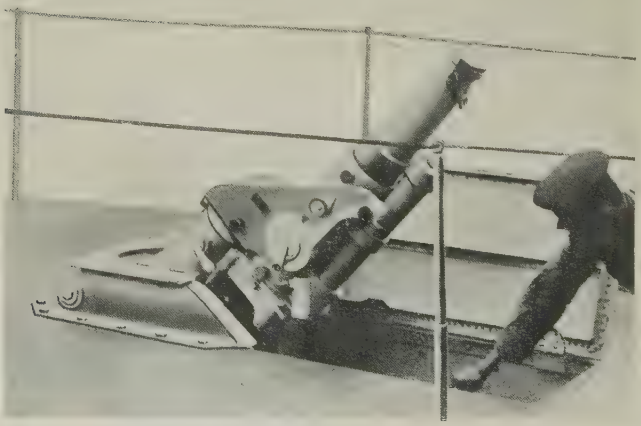
THE FIRST QUICK-FIRING GUN TO BE MOUNTED UPON A BRITISH SUBMARINE

It is housed in a special watertight well, the hinged flaps of which, when closed, are flush with the deck.



Deck Housing of the German Submarine Gun



Elevating the German Submarine Gun

It swings axially, so that when housed in the deck-well it is upside down.

ment. That is to say when stowed it is upside down, but in swinging upwards for use it assumes the correct firing position. The operation of elevating and housing is performed by a simple single lever, and it is maintained that the weapon can be brought into use or housed in the brief space of twenty seconds.

In this instance, however, instead of the trap-door lying flush with the deck, the hatch projects above the latter a few inches, this being necessary in order to accommodate the axle or bearing upon which the gun moves. The mounting proper comprises a pedestal. When the hatch is opened the release of a bolt enables the gun to swing automatically into position under the action of powerful springs, and it is held in the firing position by the aid of bolts. In this particular instance no effort is made to render the compartment for housing the gun absolutely watertight, the necessary mechanism, as well as the gun-tube, being made of metals which are impervious to corrosion by salt water. Moreover, the sensitive parts of the weapon, such as the breech sights, shoulder rests, and so forth, are rendered portable, so that they may be detached before the gun is stowed and attached upon elevation.

This gun is designed not only for attacking surface craft such as torpedo-boats, merchantmen and other submarines—for which duty it may be trained through a horizontal arc of 180 degrees—

but it is available for repelling attack from the air. To meet these latter conditions it is given a high angle of elevation. In order to facilitate the operation of the gun under such conditions special sighting arrangements are provided, while the method of firing differs from that usually practised. The manipulation of the gun requires the combined services of three men, one for loading and the other two for training and firing.

It will be seen that this weapon and its system of mounting are radically divergent from the British practice. Whereas the latter is completely self-contained and can be brought into action or housed by a single movement in four or five seconds, while it is stowed in a watertight compartment, its German rival demands the addition or withdrawal of certain parts before it may be manipulated or housed. Consequently a greater length of time is required to put the gun in or out of action. A fifth of a minute may appear trivial, but in naval operations it is often a vital span of time.

The German authorities, as well as the Krupp organisation, fully appreciated the significance of the drawbacks of the system, for both gun and method of operation subsequently underwent considerable modification. While the 7·5 centimetre arm or 12-pounder was accepted as an adequate reply to the British development, a smaller arm of 37 millimetres—1½ inches—throwing a shell of 1½ pounds was perfected and mounted upon the later craft.

In this instance, however, the gun is not mounted in the "disappearing" manner, but is built in a permanent or fixed position upon the deck of the vessel.

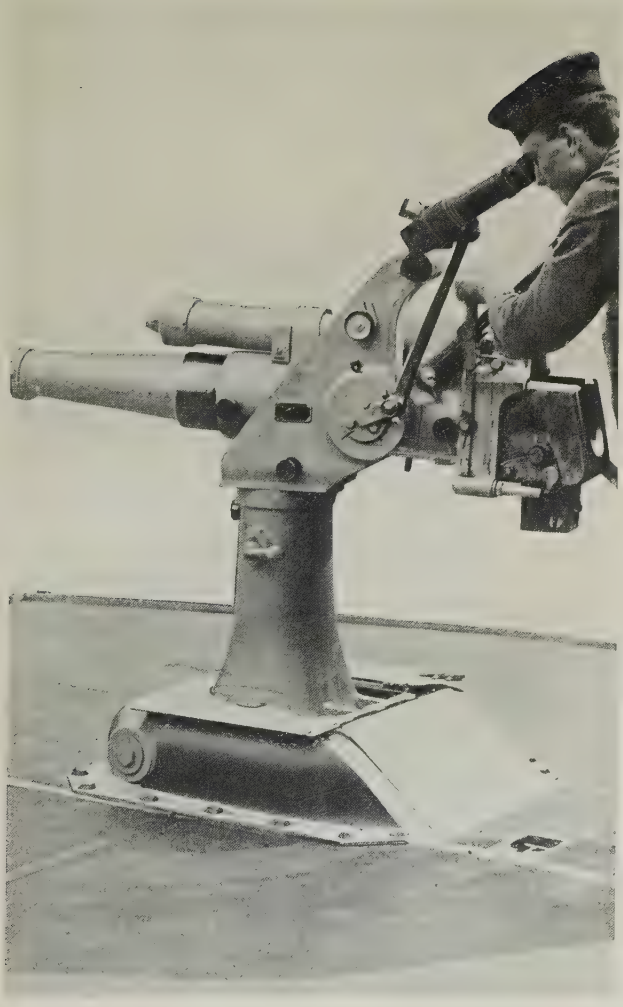
As the British armament manufacturers and submarine boat designers and builders were devoting their energies towards the perfection of a larger and more powerful weapon for submarines it was only natural to infer that the Germans would pursue a similar line of activity. As a result of animated discussion greater and more widespread attention became focussed upon this phase, while the announcement that the French and Italian navies contemplated emulating the principle, but carrying it further than had yet been contemplated, gave decided impetus to the new line of development. The Germans, following the British example, veiled their operations with considerable secrecy, and it was not until the war had been in progress about seven months that the outcome of their experiments became known.

On March 29, the German vessel *U28* was reported to be off the Scilly Islands, prowling about the mouth of the English Channel for the shipping of the Allies. The terrible blockade which had been threatened was in progress, the launching of this momentous decree coinciding with the commissioning of some new vessels for the German underwater fleet. Among the ships held up was the *Crown of Castile*, which, after the crew had taken

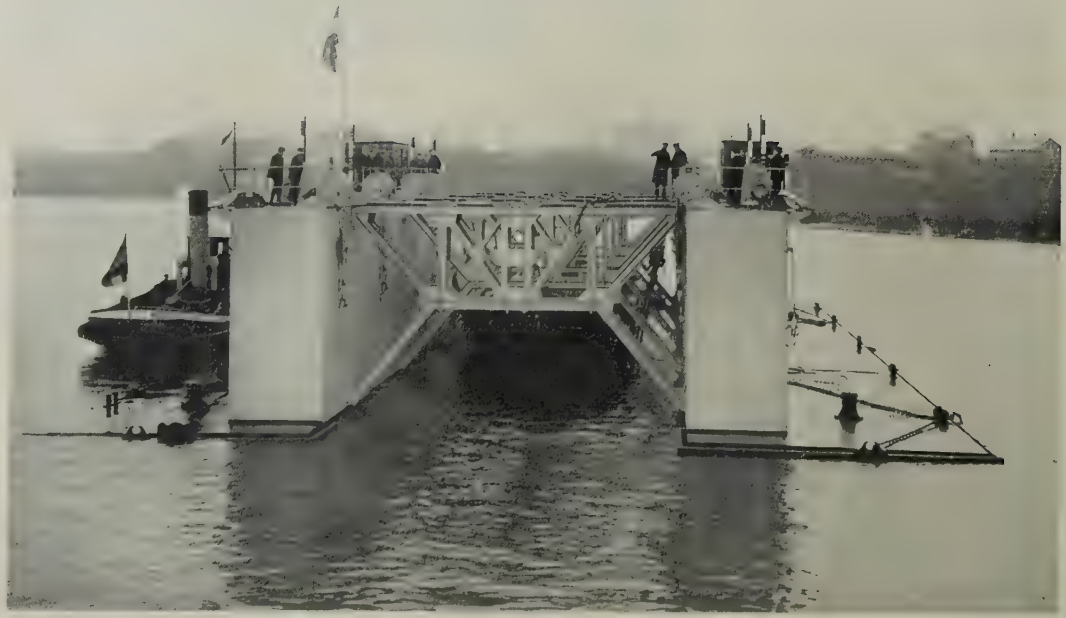
to the boats, was promptly sunk, but not in the conventional Teuton manner—that is by dynamite bombs. The crew, upon landing, asserted that their ship had been sunk by gun-fire and that the submarine in question fired 4-inch shells.

While it is possible that the latest German submarines mount 4-inch guns, it is more likely to be the 88 millimetre—3·5 inch—arm, which throws a shell weighing 25 pounds. It is practically the weapon with which the German destroyers were armed adapted to submarine conditions, particular attention having been devoted to the mounting.

The broad principles of mounting this gun to facilitate elevation to the firing position and of lowering comprise a circular platform mounted upon the upper end of a central ram in the manner of a piston and rod, with an annular guideway to ensure the even vertical movement of the gun. This ram is raised by means of compressed air, and when lifted to the requisite height is locked so as to hold it firmly. Upon this circular elevating platform is the pedestal support of the gun proper, the arrangement being such as to allow the mounting and gun to be rotated, so that the arm has a training arc of about 240 degrees. In this particular instance the gun is self-contained in the manner of its British contemporaries, is ready for instant action, and can be brought into use or housed within a few seconds. That this system of mounting and



THE KRUPP 75 MILLIMETRE (3-IN.) DISAPPEARING SUBMARINE GUN READY FOR FIRING



End View of a German Dock for Salvaging Submarines

This vessel differs from the *Vulkan*, by the engineer of which it was designed, in that the superstructure is placed between and not above the walls of the pontoon.

movement is superior to the original Krupp method is borne out by the fact that the 14-pounder guns with which some of the latest German submarines are said to be armed also now operate upon this central ram principle.

The installation of the 3·5 inch arm upon the German submarines has coincided with the protection of the deck and other vital upper works with thin armour plating, so as to render them less susceptible to light gun attack. Moreover, the fact that the crew are able to enter the turret from the interior of the submarine through a watertight intercommunicating door reduces the possibility of the vessel being surprised and sunk before she can stow her gun preparatory to submerging.

Widespread prominence has been given to accounts of the damage inflicted upon British commerce by the German submarines, but the distinction which these craft have achieved as a result of their exploits is considerably exaggerated. At the same time, however, the fact must not be ignored that the perfection of the gun for the submarine facilitated the Teutonic policy of destroying unarmed enemy ships.

The arming of submarines with heavier and more powerful guns, however, brings the possibility of combat between two of these craft well within the realms of possibility, and doubtless will compel the revision of the prevailing theory that "submarine cannot fight submarine."

CHAPTER XIII

THE SAFETY OF THE SUBMARINE

A POPULAR impression prevails that the risks in connection with the submarine are exceptionally great, and that the crews who man them are exposed to terrible dangers. It is difficult to understand why such a feeling should exist. Is it due to the fact that the vessel travels underwater and, when totally submerged, is unable to see where she is going? Does it arise from the idea that travelling underwater is unconventional? Or is it attributable to the circumstance that we have seldom heard of this class of warship except when an accident has befallen one of its number? A submarine accident has generally been wrapped in mystery up to a certain point: the vessel possibly has sunk to a depth beyond recovery so that the cause of the disaster becomes merely a matter of speculation. Catastrophe is generally complete, because the crew is invariably lost, and the episode, for it is nothing else, is apt to be magnified unduly.

As a matter of fact a submarine is exposed only to the same risks as any other type of vessel. A submarine accident is due to one of two causes—perhaps both. She founders either from an inrush

of water or from an internal explosion. The loss of a sister ship travelling upon the surface can be similarly explained. If an ordinary vessel is in collision the mishap may be of such a severe nature as to defy all efforts to stay the inrush of water. In this event the surface vessel, in common with the submarine, will float only so long as the weight due to the incursion of water does not exceed the displacement of the boat. Then, owing to the destruction of all buoyancy, the vessel must sink to the bottom in accordance with the laws of Nature. In the second instance, explosions are equally likely to occur on the surface vessel. It may be a boiler explosion, or, as in the case of the *Irene*, *Bulwark* and many other ships, it may be due to the detonation of the ammunition.

So far as the submarine is concerned, the first-named danger is the only one that is dreaded to-day. The second, owing to the use of Diesel instead of gasolene motors, has practically been eliminated, the explosion of a Diesel engine being an extremely rare occurrence. The fuel offers no danger whatever, for the simple reason that the heavy oil employed does not emit gases in sufficient quantities at normal temperatures to be inflammable. The only gas danger that is still encountered is the emission of hydrogen while the charging of the electric accumulators is in progress, but, seeing that this duty is performed only when the boat is upon the surface and when the interior is

thrown fully open to the outer air, thereby offering the hydrogen an opportunity to escape, this risk is reduced to such slight proportions as to be considered negligible.

In the early days of submarine navigation, accidents appeared to occur with disturbing frequency. But it was not the foundering of the boats, so much as the attendant loss of life which excited public comment and precipitated the feeling that the underwater fighting ship was decidedly dangerous. But those were days when searching and unremitting investigation was imperative: when, little or nothing being known about the subject, it was necessary to discover as much as possible for future guidance. Work of this character is unavoidably attended by serious hazard. A certain amount of risk must be incurred in order to solve the various technical problems, many exceedingly abstruse, as they arise, but when investigations are conducted as carefully as human ingenuity can contrive, the results are positively productive of an immense quantity of valuable knowledge with the minimum risk to human life. Without the data gained by the loss of vessels and lives it is quite safe to assert that the British submarine fleet would never have been brought to its present state of high efficiency and reliability.

As is well known, the British submarines belong to what are called the " diving " class, as opposed to the submersible, which is claimed to submerge

upon an even keel. The advocates of the latter school maintained that the disasters to the early British craft arose from the tendency to "dive" so precipitately as to plunge, and the loss of the *A4* was quoted in support of this argument. But, as the official records prove, the boat in question was lying at rest in a submerged condition at the time, and was carrying out experiments in submarine signalling. She was in flag communication with another vessel to which she signalled the results of the tests by wig-wagging, the flag being manipulated through an open ventilator which projected slightly above the surface of the water for this purpose. A passing wave struck the open ventilator and water poured into the interior of the vessel. Efforts were made to close the ventilator, but the flagstaff prevented the fulfilment of the task, with the result that the water, continuing to enter, submerged the ventilator, finally sending the vessel to the bottom by destroying her remaining buoyancy. The majority of the other losses occurred through the submarines either being run down by passing surface craft, as in the case of the *A1*, or from an explosion of accumulated gasolene fumes within the boat, the latter being ignited by the production of an electric spark either from the movement of a switch or some other part of the electrical machinery.

The worst feature of the submarine which strikes the sentiment of the public is the poor opportunity of escape afforded to the crew in the event of an

accident while submerged. " Drowned like rats in a trap " is a popular term for graphically describing the plight of the underwater fighting men when sudden disaster has overwhelmed the boat. " Cannot mechanical ingenuity or inventive genius contrive some means of giving the men a fighting chance for their lives? " argues the uninformed critic.

As a matter of fact, considerable ingenuity and experiment have been expended in this direction. While the early boats may deserve being likened to rat-traps the term is not applicable to modern craft. The preservation of human life has been a guiding maxim for some years past, and every safety device which can possibly assist this end, without reducing the efficiency of the boat or curtailing its manœuvring capacity, has been incorporated. For instance, all German, and certain American, submarines carry a buoy containing a telephone transmitter, receiver and a length of wire connected to another receiver and transmitter within the boat. In the event of an accident precipitating foundering, this buoy can be released from within the vessel. It immediately rises to the surface, where it compels attention since its presence signifies that something untoward has befallen the boat to which it belongs. Incidentally it also marks the scene of the mishap. By retrieving the buoy, telephonic communication can be established with the commander of the submarine, and

valuable information concerning what has happened to the boat and the condition of the crew can be obtained.

The value of this simple accessory has been demonstrated upon several occasions, notably in the case of *U3*, which sank in Kiel Harbour on January 17, 1910. Directly the buoy telephone was picked up the welcome news was gathered that the boat was intact, that the crew was quite safe, and that no apprehensions need be entertained during the ensuing forty-eight hours, for which period there was a supply of oxygen on board to revitalise the atmosphere within the boat. As the German Navy is equipped with a submarine salvage vessel *Vulkan*, described in another chapter, the surface workers were enabled to perfect their plans for raising the vessel. The sunken submarine was retrieved satisfactorily, and the crew effected their escape through the bow torpedo tubes owing to the vessel being lifted bow first. The commander, lieutenant and helmsman, however, subsequently lost their lives. These fatalities, however, might have been avoided, since the whole crew could have been taken off when the vessel first came to the surface.

One danger to which the crew of the submarine is exposed is sudden incapacitation arising from the force of collision. If this be of a violent character, the men within are liable to be stunned by the shock, and the boat left to its own devices until

the men recover their senses. This is a contingency which demands special attention. In the latest Holland boats, sinking from this cause is ingeniously and effectively prevented. There is a simple hand-control which enables a large amount of buoyancy to be created rapidly at any depth by the speedy emptying of the ballast tanks under the combined action of the pumps and air at a very high pressure. In addition a novel automatic device is fitted. This is designed to prevent the vessel sinking below a certain depth, the latter varying, of course, according to the setting of the apparatus. Should the crew be bowled over by the shock of a collision and the submarine ship sufficient water to cause her to founder, directly she reaches the critical depth the automatic apparatus comes into action, empties the ballast tanks, and also starts the pumps, which are very powerful, emptying the interior. The result is that sufficient buoyancy is speedily imparted to the submarine to induce her to rise to the surface independently of any action on the part of the crew.

The British Admiralty has been especially energetic in devising ways and means of enabling the members of a submarine crew to save themselves in the event of disaster. They are provided with helmets, resembling those used by firemen to facilitate entrance to a burning building full of dense smoke or poisonous gas fumes. The life-saving dress itself, which may be easily and

instantly donned, is stowed in its own helmet and hung up in the "air-locks" of the submarine. A 12-pound weight is attached to each dress to enable the wearer to keep his feet, but if he finds that he does not possess sufficient buoyancy to regain the surface he can slip this weight upon emerging from the submarine. On the other hand, should he have adequate buoyancy he retains the weight until he reaches the surface, when he abandons it. The weight of the dress complete is 16 pounds, and it can be put on within 30 seconds.

Inside the jacket is a pocket containing an air purifier and regenerator. This comprises a certain charge of a special chemical compound known as oxylithe, the property of which is to emit pure oxygen by contact with the water vapour of the breath, and to form caustic alkali which in turn absorbs the carbonic acid gas exhaled in breathing. Consequently the air within the helmet is preserved in a pure condition and contains the normal volume of oxygen to sustain respiration. By this means the air within the helmet is purified and re-oxygenated, being used over and over again until the oxylithe becomes exhausted. Sufficient oxylithe is carried to enable the wearer to breathe freely, safely, and without suffering any physical ill-effects for some ninety minutes, and this is estimated to be adequate to sustain him until he can leave the submarine wreck and regain the surface.

When this is accomplished, the supply of oxylithe,

if any remains, may be husbanded against further emergency. In the front of the helmet is a small window which may be opened, thereby permitting the wearer to breathe the pure outer air. Should there be no means of immediate rescue the wearer is placed in no danger. His dress is provided with inflatable pockets which he can blow out, and these will provide sufficient buoyancy to keep him afloat for an indefinite period. The helmet, when the man is floating, acts as a buoy, is readily distinguishable, and will thus guide a passing vessel to the spot. The only danger confronting the wearer is from thirst and starvation, but this is a problem the solution of which is somewhat difficult within the severe restrictions of the life-saving apparatus, which is primarily designed to offer the men who go under the sea in ships a practicable opportunity to regain the surface in the event of their vessel foundering. Possibly this problem might be overcome by fitting the dress with a small emergency ration such as is served out to soldiers.

But, it might be asked, how can the crew don these garments when their vessel is damaged so severely as to admit the water? If the hole is made in the hull at a point below the deck or conning tower the inrushing water will prevent the air within the vessel from escaping. The latter will be driven towards the roof of the vessel, and will be compressed until at last it attains a pressure

corresponding with that of the water outside. It has been found possible, in designing these vessels, to dispose bulkheads in such a manner as to serve as air-traps, and that without affecting the efficiency of the boat in any way. The dresses are stored within these air-traps, or "air-locks" as they are termed, to which the members of the crew make their way in the event of disaster. There they can assume their life-saving dresses without difficulty or danger, subsequently making their escape from the vessel through the conning tower or safety hatches.

In the German Navy the members of the crew are equipped with outfits which are reminiscent of the Draeger apparatus, used for rescues after coal-mine explosions, with certain modifications to fit it to the new duty. The dress is designed to fulfil three requirements: to ensure satisfactory respiration under variable water pressures; to provide sufficient buoyancy to enable the man to regain the surface; and to keep him afloat for a considerable period.

The apparatus is small and compact, so that it occupies little space. Its total weight is 13¼ pounds, and it is equipped with a weight of 12½ pounds. It is put on in the manner of a waistcoat, the respirator fitting over the mouth and nose. The ears and the remainder of the head are left exposed, though a pair of large goggles serves to protect the eyes. The dress is somewhat more complicated

than that used in the British Navy, since the breathing apparatus proper comprises an oxygen cylinder, a potash cartridge for absorbing the exhaled carbonic acid gas, and the breathing bag carried upon the back, while the action of the apparatus itself is not automatic, but has to be adjusted by hand-controlled valves. Upon reaching the surface the man can remove the apparatus from his mouth and nose and so breathe the open air, but the upper part of his body is protected and he is kept buoyant by the swimming vest, which is not discarded until he leaves the water.

In order to facilitate escape from a wrecked submarine the latest vessels of the Holland type, built for the American Navy, are divided into five separate compartments by complete transverse steel bulkheads, each fitted with a watertight door. Hatches are fitted to all but one of these internal compartments. As a result of this arrangement the men in each compartment are able to escape through the hatch provided, instead of rushing to a common point within the boat. By means of a special system of partial and completed bulkheads an air-lock is automatically formed in each compartment, so that when an accident occurs, the men merely don the helmets carried in the compartment in which they are working, and escape through the hatch immediately above them.

It must be admitted that these safety devices are of little value under conditions of war. If a

submarine be sunk by torpedo the widespread tearing of the hull would prevent the formation of air spaces within the vessel, while the shock of the explosion would probably stun if it did not kill the crew outright. A similar result would doubtless attend sinking by heavy gun-fire, while ramming by a destroyer travelling at high speed would indubitably smash up the submarine so completely as to destroy every chance of escape. In order to guard against such contingencies many novel proposals have been made, such as detachable conning towers and emergency buoys capable of containing the crew, which upon being cast adrift, are intended to float to the surface. However practicable such projects may have been in the early days they are quite out of the question to-day when a submarine carries a complement of 40 men.

Nevertheless, all things considered, it will be seen that the submarine is every whit as safe as her consort restricted to surface travelling. Whereas the members of the crew of the latter type of vessel are able to don lifebelts to keep themselves afloat, the man in the submarine is equipped with a life-saving device which will carry him to the surface and keep him afloat until rescued. Under war conditions a similar parallel may be drawn. The men on board a warship, whether it be a battleship or a destroyer, have no more chance of escaping than those operating under the water. So that no

matter from what point of view the submarine is considered the element of danger is no more pronounced than in any other type of craft.

The present-day submarine may be said to be as safe as human ingenuity, in the light of current knowledge, can contrive. Great Britain has certainly paid the penalty in this effort to secure greater safety, since during the ten years preceding the outbreak of war some 77 officers and men were lost through accidents to submarines, out of a total casualty list of 200 officers and men from submarine disasters for the whole world. But the British death roll was associated with the early vessels: was connected with boats which were more or less experimental. As the submarine has developed and successive classes have been produced, the casualty list has decreased. The United States was the most fortunate of all the Powers, for, until April 1915, its navy did not record the loss of a single submarine nor the loss of a single life in connection therewith. This "clean slate" was marred by the loss of the *F4* with the whole of her crew in 250 feet of water in Honolulu Harbour.

CHAPTER XIV

SALVAGE VESSELS FOR SUBMARINES

FIVE or six years ago no naval topic was so vigorously discussed as the salvaging of submarines after an accident. It was not a question which much affected naval circles: it was rather a matter of public outcry. The average individual, when he learned of a disaster to an underwater fighting ship, shuddered at the plight of the men who were within her, and who, to his mind, were condemned to a slow and terrible death by asphyxiation. Heart-rending pictures of their sufferings were painted, but it is doubtful whether the situation was correctly interpreted, in view of the experiences of the courageous commander of the Japanese submarine boat which foundered with the loss of its crew. When the vessel was recovered a wonderful human document was retrieved—the journal of the commander who had jotted down his sensations up to the moment of losing consciousness. In the days of the gasolene engine the probability is that the hapless men were first overpowered by the intoxicating fumes of the motor spirit, which, acting as an anæsthetic, spared them the final agony of fighting desperately for their breath.

But the public voice refused to be silenced until something was done. The masses learned from more or less reliable sources that a reserve of air sufficient to keep life sustained for several hours was carried in the compressed air flasks, and the popular imagination being more fantastic than practical, it was argued that the vessels, being relatively small, should be capable of ready salvage. The loss of life incidental to such accidents might either be lessened or entirely avoided by the possession of ample wreck-raising facilities combined with promptitude of action. The British Admiralty, which was accused of being indifferent to the situation, was bitterly assailed. The acquisition of a complete salvage equipment and its maintenance in a condition of constant readiness was demanded.

The public clamour in this connection was due in a large degree to the wonderful appliance which Germany possessed for this special purpose. According to German reports it had proved remarkably successful. Unfortunately, the general public, in its wild enthusiasm, lost all ability to view the matter dispassionately and in its proper light. There was one difference between British and German submarine methods, and this difference constituted the crux of the whole problem. British submarines, even in the earliest days, were designed and constructed for one express purpose—to operate in deep water and the open sea. On the other hand the German submarines scarcely ever ventured

away from harbour, and all manœuvres were carried out in land-locked bays and fjords in calm weather. Even when war was declared there was a certain manifestation of hesitancy when open-sea tactics were taken in hand: it was merely the intrepidity of the commanders of certain craft who, venturing to sea, indicated the manner in which submarine warfare might be waged to the profit of Germany.

The German, in his admiration of his own handiwork, never hesitates to emphasise the wonderful submarine salvage plant which the Vaterland possesses, and never tires of relating the glorious raising of the *U3*. But it is difficult to realise how anything but success could have resulted in this instance. *U3* sank in Kiel Harbour! The submarine salvage vessel was duly summoned, but, curiously enough, she was not responsible for the saving of life. A powerful floating derrick in the harbour grappled, secured the sunken submarine, and lifted it until the bow projected above the water. Then twenty-seven of the imprisoned crew escaped through the torpedo tube. The captain and two lieutenants elected to remain in the vessel as there was no danger, until she was lifted by the submarine salvage vessel *Vulkan*, which was hurrying to the scene. The decision cost them their lives, for one of the ventilators was unexpectedly smashed, there was a swift inrush of water, and the vessel was flooded.

The *Vulkan* is a kind of pontoon dock. There

are two hulls or pontoons, 230 feet in length, with sufficient space between them for the floating of a submarine. At a suitable height there is a ledge or shelf upon the inner wall of each hull which serves as a support to a movable floor. Spanning the well between the two pontoons are two massive gantry cranes equipped with powerful lifting tackle and driven by large electric motors.

The *modus operandi* is very simple. The *Vulkan* steams to the spot and manœuvres over the wreck so as to bring the latter between the two hulls. Water is then admitted into the compartments of the two walls, causing the whole vessel to settle down. When submergence has been carried to the desired degree the movable floor is withdrawn. Simultaneously divers descend and attach chains to slings which have been passed fore and aft round the submarine, or else hook the chains to large eye-bolts which are riveted into the hull of the submarine at the stem and stern respectively.

The electric cranes are set in motion and the submarine is lifted free of the sea-bed and drawn up into the well of the salvage vessel. Hoisting is continued until the submarine is raised above the shelves carrying the portable floor, which is now replaced and the submarine is lowered until she rests firmly upon keel blocks placed upon the floor. At this point the two hulls of the vessel are emptied simultaneously and evenly until at last the vessel rides at her normal draught with the submarine

DECK VIEW OF A GERMAN SUBMARINE SALVAGE DOCK

This photograph shows the cables and winches for lifting the sunken vessel.

A Flotilla of German "U" Boats lying in the Kiel Canal

The flat deck or superstructure characteristic of the Lake design is distinctly noticeable.

high and dry and in a position to enable access to be gained to any part of her body.

The *Vulkan* has a lifting capacity of 500 tons at a speed of 83 feet per hour. The salvage of the *U3* was completed in about three hours. The operation is interesting, and, when working in the calm waters of a harbour, is undoubtedly very effective. But how would it fare in a sea-way? Then the conditions become vastly altered. Wind, sea and tide affect the issue very vitally. Upon this point German experience is silent, for the simple reason that the much-vaunted *Vulkan* has never yet been called upon for duty in such circumstances. But it is not a difficult matter to appreciate that the performance in Kiel Harbour with *U3* could not be repeated in the open sea unless climatic and other conditions were exceptionally favourable.

In France the Ministry of Marine was sharply assailed by the public for not anticipating the German movement. The agitation reached its climax in connection with the delay in lifting the unfortunate *Pluviose*. To placate public indignation the authorities sanctioned the construction of a vessel of special design, capable of raising 1000 tons from a depth of 120 feet. To a certain degree this vessel resembles the German craft. There are two hulls, connected at one end, between which there is a clear space of 41¾ feet, while the over-all length is 322 feet. This well is spanned for the greater

part of its length by a massive and intricate lattice-work steel roof carrying the hoisting machinery. Some idea of the proportions of this craft may be gathered from the fact that it displaces 2,300 tons.

As mentioned in a previous chapter, Major Laurenti, in designing his testing dock, adapted it to the work, if necessary, of lifting sunken submarines. In this instance, however, the whole procedure is somewhat different. Whereas with the German and French salvage craft the wreck can be lifted high and dry into the well between the two hulls, in the Laurenti dock, where the hoisting chains are attached to slings passed round the submarine, the wreck is hoisted upwards beneath the salvage craft, and cannot be lifted clear of the water. The procedure is similar to that which would be followed if ordinary lighters were employed. The wreck is raised a certain height, and the dock is then towed inshore until the wreck once more rests upon the sea-bed. Then it is given another lift to be hauled a little closer inshore, these successive lifts being continued until at last the wreck is carried into port or is beached, and an opportunity is afforded for entering it.

So far as Great Britain is concerned—and in this respect she is emulated by the United States—no submarine salvaging craft of a special type has been constructed. The difficulties encountered in raising the sunken British submarine *A3* are still fresh to the memory, and incidentally they brought home

the fact that the salvage of a submarine which has foundered in deep water exposed to the full action of wind, sea and tide is virtually hopeless. As a matter of fact, no established method of raising a submarine from a depth of 120 feet in the open sea has yet been devised. The conditions of raising a submarine are so vastly dissimilar from those pertaining to other aspects of marine salvage as to render the application of tried methods impossible.

It is difficult for the ordinary reader to realise the plight of a submarine which has gone to the bottom for some apparently inexplicable reason. Of course, if the ship has been rammed by a surface craft, and has been cut nearly in two there is no hope of saving life, while the retrieving of the wreck is not worth the expenditure of time or money. But ignoring the last-named cause of the accident, the wreck either is intact or damaged. If she is intact there is no immediate danger. The air supply within the vessel is adequate for forty-eight hours or more, and if the submarine is fitted with a detachable telephone buoy, such as constitutes a feature of the German craft, it is possible to communicate with the commander within and to gather some idea of the situation. Possibly a leak has developed, and the water, neutralising the reserve buoyancy possessed by the submarine in the submerged condition, has compelled her to sink like a stone.

In this event the situation is not desperate. The water which gains the interior, provided it is from a point below the roof, cannot occupy the entire space, inasmuch as the air within the vessel, being unable to escape, must become compressed until at last it attains a point coincident with the hydrostatic pressure. In this space, or air-lock, the crew are able to don their life-saving apparatus with which submarines are fitted, and to effect their escape through the hatch. But the water can in some cases be expelled. A diver may descend with a hose and connect it with a special socket in the hull of the submarine. Through this hose compressed air may be driven into the submarine and the water gradually expelled. In so doing, the buoyancy is restored to the vessel, with the result that she will rise to the surface under her own effort.

In the event of the boat being damaged, the only solution of the problem is to lift her bodily. It appears to be a simple operation to attach hooks to eye-bolts riveted in the vessel's hull or to slings passed round the vessel, but as a matter of fact it is a task which bristles with difficulties. In the first place an absolutely smooth sea is imperative, while the effects of currents and tides have to be taken into consideration. The work may be possible only between tides, and then necessarily for very short intervals, while the periods during which a diver is able to work below water, especially at

great depths, are exceedingly brief. But assuming that the preliminary preparations are completed satisfactorily, the real dangers and difficulties are encountered when the actual lift commences. If the pontoons should be rolling, even very slightly, there is grave risk, for the moment the lift is attempted there arises the danger of bumping the submarine upon the sea-bed, and that would speedily seal her fate, especially if the bumping were severe. Again, the strains upon the hoisting gear under such conditions would be enormous.

Raising a sunken submarine in open water must be performed quickly, every advantage being taken of the prevalence of smooth water and absence of wind. This means crowding on labour, but no matter how strenuously one and all may toil, success is always speculative. Hoisting is certain to be a slow operation in the most favourable circumstances, with the result that success depends essentially upon the continuation of favourable atmospheric and sea conditions, which in such a latitude as Great Britain is scarcely to be expected.

The imposition of the 200-feet submergence test upon American submarines has necessitated the training of divers to descend to such a depth to complete any work which may be necessary. In the American Navy the preparation of men for duty at such a depth has developed into a special undertaking. The result is that many skilled divers are now able to venture to a depth of 200 feet or more,

the record being 274 feet in Long Island Sound. In the salvage of the *F4*, which sank in Honolulu Harbour, the divers were called upon to descend to a depth exceeding 250 feet.

Prevention is better than cure, and, though loss of life is to a certain extent inseparable from all seafaring operations, every life-saving device at present available is followed by the men who specialise in the design and construction of the submarine. Hence the ceaseless indefatigable efforts to lessen the possibility of accidents. In view of the great depths to which a submarine now descends and the increasing tendency to use it in deep open waters, those who are responsible for the vessels have no faith in salvage operations. "Give the men a chance to escape and write the sunken vessel off as a loss," is their creed. It will cost more to lift a submarine from, say, a depth of 200 feet than she cost originally, while the probability is that she will be useless for further service when retrieved. Examination of the wreck may yield information of technical value, and enable one to profit from disaster, but nothing more.

CHAPTER XV

THE GERMAN SUBMARINE

One of the most remarkable features of contemporary naval engineering history is the growth of Germany's underwater fighting fleet. One must not forget that Germany had not entertained the submarine seriously at the date when it had been definitely accepted as a fighting unit by all the Great Powers, who were committed to substantial construction programmes. But Germany pursued her traditional "wait and see" policy. The other nations were pioneering the movement, were engaged in ceaseless expensive experiments, and were striving might and main to bring the idea to the practical stage. The wily Teuton, as usual, was not disposed to embark upon experiments. The progress of the various Powers was followed closely, and from the sum of the results German naval scientists were slowly but surely evolving a type which should possess all the advantages of the most efficient and approved craft with none of their defects.

The situation recalls the policy which Germany pursued in regard to aircraft. She preferred to wait and to follow the developments of other nations,

then, when they had reached a certain position in the task of development and perfection, to make this her starting-point. Such a proceeding provided her with a standard or established principle and foundation upon which she could build with the minimum of expense and the maximum of speed.

So it was with the submarine. Both the Holland and Lake types were introduced to Germany, but she preferred to bide her time before making a definite decision. The results of the respective experiments, combined with the outcome of the comparative official tests in the United States, proved of immense value to the German Admiralty. Finally, when it was decided to introduce the submarine into their Navy, neither of the two foregoing proved principles were adopted. They followed one that had been evolved by the firm of Krupps. The policy of strict secrecy which Great Britain followed unswervingly was exasperating to the German Admiralty, since in all her naval developments British practice has been slavishly followed. But the veil of secrecy could not be penetrated, although the most strenuous endeavours to ascertain what Britain was doing and what she had done were made. The situation was rendered additionally complex because Germany could not even profit from Britain's submarine disasters. The evolution of a new design of submarine, warship or any other product of human ingenuity is invariably productive of accident, but the British Admiralty pre-

served a discreet and profound reticence concerning the causes of such accidents to submarines as marked her early efforts in this branch of warship engineering. This course of action was regarded with misgiving, if not irritation, by the British public, but to-day the benefits of such silence are apparent: we gave nothing to assist our enemies.

The Krupp submarine was the creation of an engineer named Equevilley, but the modern craft is generically known as the Germania type. It is avowedly a combination of all the successful types of submarines in service to-day which are accepted as being the best achievements of their respective creators. There is the spindle form of the Holland, the ship-form superstructure of the Lake, as well as the outstanding and approved features of the Narval and its successors of the French Navy designed by Monsieur Laubeuf. In fact, the German submarine when afloat is described as being closely similar to a torpedo destroyer.

In these circumstances, it is difficult to state with any degree of accuracy which type of design has been the most influential in the development of the German submarine. But in German circles the Germania is surrounded with quite as much secrecy as envelops the Vickers-Holland craft in Great Britain, although the fundamental features of the German *unterseeboote* are somewhat more familiar, for the simple reason that up to two or

three years ago the Krupp firm, confident in the superiority of its design, was prepared to supply underwater fighting vessels to all and sundry, and, in fact, furnished several of these craft to many of the Powers, including Russia, Austria and Norway. The early "U" boats are virtually duplicates of the boats supplied to the foregoing countries. In fact, so far as secrecy is concerned in Germany, this is confined rather to developments during the past three years, and these refer more particularly to dimensions, displacements, armament, radius of action, and number of the craft under construction to the order of the German Admiralty. The latter was taken somewhat aback when the numerical and fighting strength of Britain's underwater fighting fleet became realised, and from that moment every effort was made to reduce the degree of British numerical advantage.

The Germania submarine is regarded as being of excellent design and of first-class fighting value, while the latest types are notable for their radius of action, as already explained. In profile they follow the ship form, characteristic of the American Lake design, although the hull is of semicircular form (Fig. 6). There are two hulls, the inner being circular throughout its length. It is divided into three main sections, that in the centre being cylindrical, while the second and third sections, representing the stern and bow respectively, are conical. The inner hull, however, terminates some consider-

able distance from the two ends of the outer hull, the intervening space at either extremity being occupied by ballast tanks. In fact, the whole of

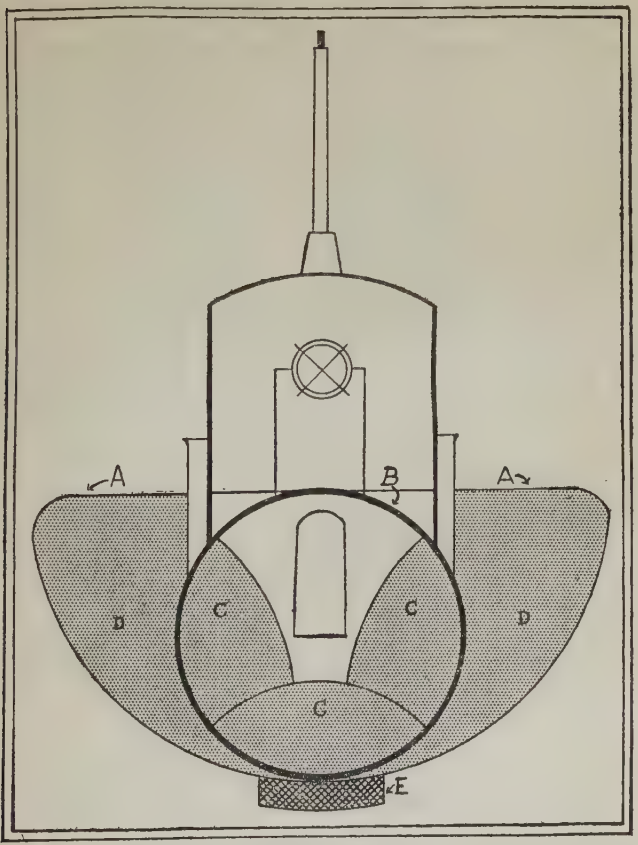


FIG. 6.—SECTIONAL DIAGRAM THROUGH CONNING TOWER OF A GERMAN SUBMARINE

AA, outer hull; B, inner circular hull; CCC, inner water-ballast tanks; DD, outer water-ballast tanks; E, detachable safety keel.

the surrounding space between the inner and outer hulls from end to end is subdivided into tanks, the result being that the inner hull is virtually protected by a surrounding wall of water and oil, since the fuel supply is carried in this double wall. Subdivision is carried out by transverse bulkheads, somewhat in the manner of the latest trans-Atlantic liners, which have an inner and outer skin. This compartmenting contributes to the safety of the vessel for the reason that a certain number of these compartments may be flooded, or, rather, exposed to the outer sea, without endangering the safety of the vessel. The disposition of these compartments and their employment in the direction of carrying oil and serving as water ballast tanks may be appreciated by reference to the accompanying diagrams (Fig. 7).

The inner hull or submarine proper is of strong construction, being designed to withstand the water pressure which is experienced at a depth of 100 feet. Thus it will be realised that, should the outer shell be broken, there is no immediate risk to the crew in the event of her foundering to a depth within the above limit: the plating will not be forced inwards by the water pressure, neither will the seams be started under the same influence.

Each of the three longitudinal sections of the inner vessel is complete in itself; that is to say it contains some complete part of the necessary mechanism. The first or bow section contains a

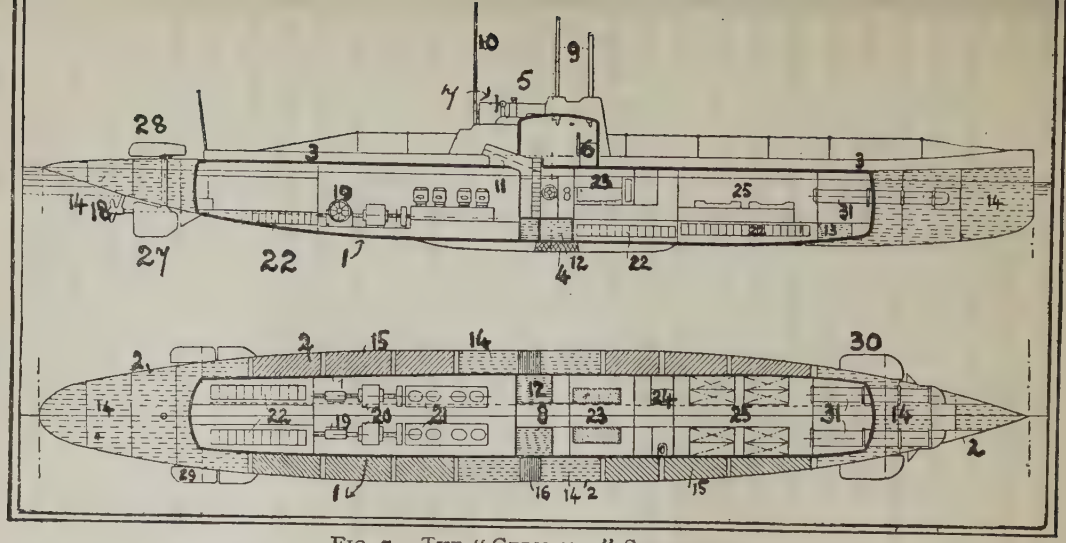


FIG. 7.—THE "GERMANIA" SUBMARINE

(1) Inner hull. (2) Outer hull. (3) Deck. (4) Detachable safety keel. (5) Conning tower. (6) Conning tower steering wheel. (7) Bridge steering wheel. (8) Central driving position. (9) Periscopes. (10) Signal mast. (11) Torpedo hatchway. (12) Inner water-ballast tanks. (13) Torpedo-trimming tanks. (14) Outer water-ballast tanks. (15) Fuel oil tanks. (16) Lubricating oil tanks. (18) Propellers. (19) Reversing gear. (20) Electric motors. (21) Oil engines. (22) Accumulators. (23) Officers' quarters. (25) Sleeping berths. (27, 28) Steering rudders. (29) Stern hydroplanes. (30) Forward hydroplanes. (31) Torpedo tubes.

part of the secondary battery as well as the torpedo tubes and supply of these missiles. The central or amidships section contains the internal water ballast tanks, the conning tower, steering and control gear for navigating the boat, either when on the surface or when submerged, as well as the periscope and indicators. The third or stern section is devoted to the machinery space comprising the internal combustion motors disposed in two sets upon either side of a central alley, as well as the electric motors for underwater travelling and the second instalment of the secondary battery. The vessels are fitted with twin screws, and in the machinery space is the apparatus for reversing the propellers. In addition to the two or more torpedo tubes carried in the bow of the vessel one or more tubes are placed upon the bridge.

The vessel is equipped with bow and stern horizontal rudders or planes for steering in submerging and ascending to the surface as well as the ordinary rudder for steering in the horizontal plane. The complement of the submarine naturally varies according to its size, displacement and designed purpose, the smaller craft, allocated to operations in home waters, that is in the vicinity of ports and harbours, carrying ten men, while those delegated to ocean-going duties range up to forty.

The motors for driving the vessel upon the surface and also for driving the electric generators for charging the accumulators are of the Diesel type

using heavy oil. In the latest craft they are of sufficient size to develop from 2000 horse-power upwards per shaft.

Special attention has been devoted to the air supply. When the vessel is travelling awash, the heated air in the engine-room is discharged into the atmosphere in the usual manner, fresh supplies being drawn from the outer air, but when she is submerged the air circulation system is somewhat more complicated. Any heated air remaining in the engine-room, after changing from the cruising to the submerged condition, is passed through ducts to purifying and cooling chambers and then returned to the engine-room. By this means the latter is speedily cooled with refreshing atmosphere. The vitiated atmosphere of the other quarters of the vessel is treated in a similar manner, only in this instance, in the purifying and cooling process, it is re-invigorated by the restoration of its oxygen content, which is accomplished by the aid of chemicals. Owing to the perfection of the air-circulating system, these vessels are able to remain submerged from twenty-four to forty-eight hours upon end without entailing upon the crew the slightest inconvenience in regard to respiration.

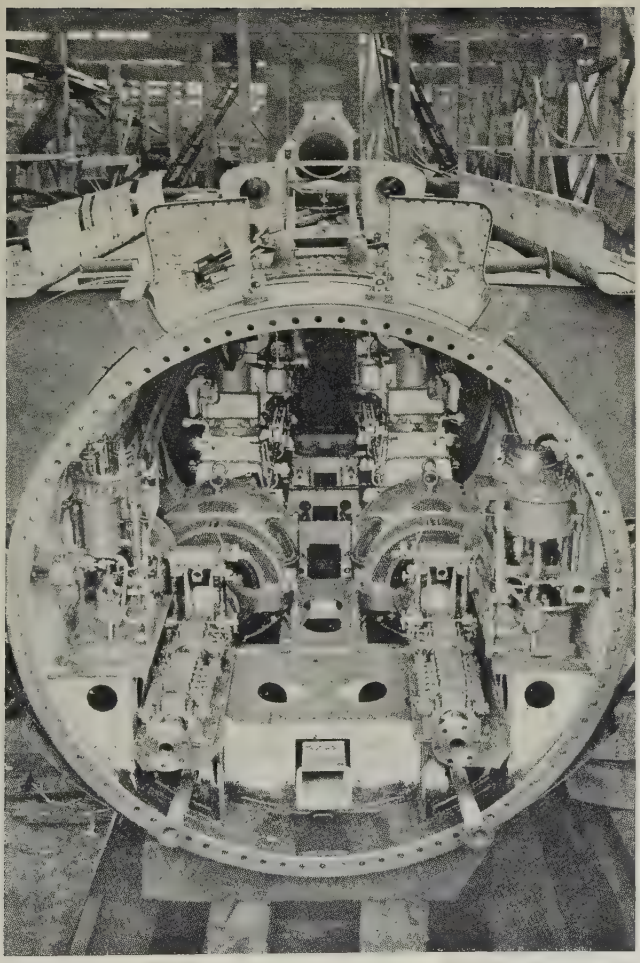
The engine-room is fitted with pumps for emptying the water-ballast tanks as well as for charging the torpedo tubes. The fuel is led from the main supply tanks between the two hulls to a reservoir in the engine-room, the loss in fuel weight arising

from combustion being compensated by the automatic admission of water ballast.

The internal water-ballast tanks, which are carried in the central section of the inner hull, are for the purpose of compensating the variations in stability arising from the inclination or declination of the vessel during descent and ascent. This central compartment also contains the controlling gear. The diving rudders are so disposed that they can be moved simultaneously by one man by means of a wheel.

The conning tower is of sufficient dimensions to hold from three to five men. Here are the eye-pieces of the two periscopes, which range from 15 to 20 feet in height, *i. e.* project above the roof of the conning tower to this extent. To each periscope is attached an electric motor to rotate the latter through its arc of movement. The length of the periscope tube is sufficient to enable the boat to travel, when submerged, at a depth which places it beyond the reach of gun fire. The conning tower is connected with the interior of the submarine through a hatchway or trap-door. This constitutes the only opening in the inner hull, and, if the occasion so demands, the hatch may be closed and rendered watertight, so that water cannot penetrate through this space into the interior so long as the inner hull remains intact.

While the Germania submarine has been brought to a very high standard of perfection, accidents



Interior of a German "U" Boat
Showing engines and the inner circular hull.

SWEDISH SUBMERSIBLE "HVALEN" BUILT AT SPEZIA [*Cribb*

This vessel aroused considerable interest by travelling from the Italian shipyard to Christiania unaccompanied, which at that time was the longest journey ever accomplished by a submarine. She made only one intermediate call at Portsmouth [illegible]

cannot be completely averted. During the opening months of the war the German Navy lost a vessel which displayed a greater predilection for the bottom than the surface of the sea. But, as described in another chapter, they are well provided against such contingencies. To facilitate the raising of these craft the outer hull is provided with heavy hooks to which hawsers can be attached. The vessels are also equipped, as is the Lake submarine, with a heavy emergency keel, the weight of which varies from 5 tons upwards according to the displacement of the vessel. This can be readily cast off when necessary to facilitate the return of the boat to the surface. Among the many accessories with which these craft are equipped is a telephone. A length of line is carried within the vessel. The free end of this wire is fastened to a small buoy which is attached to the outer hull of the submarine by a special device. This buoy can be released automatically from within, when it immediately rises to the surface with the wire. This buoy, upon being retrieved by a surface vessel, enables communication to be established between the latter and the submarine below.

These submarines can be submerged quickly according to the statements of the designers. From three to five minutes are required to seal the vessel preparatory to submerging. The latter operation, it is stated, can be completed within fifteen seconds. The return to the surface is equally rapid, owing

to the ease and celerity with which the water-ballast tanks can be emptied. To facilitate this task there is a compressed air reservoir in which the air is compressed to a pressure of about ten atmospheres —approximately 150 pounds per square inch—and this is kept charged to this limit so as to be available at a moment's notice.

The Germania vessels are designed to withstand the water pressures which are encountered up to a depth of 170 feet—74 pounds per square inch. While this depth is beyond that at which such craft are normally required to operate, yet this precaution provides a measure of safety for the craft and crew in case of an accident within these limits, because there is the possibility of the vessel being salvaged, as already mentioned, if such a mishap should arise.

In the later craft, which are designed for open sea operations, the protection is carried to a still greater degree. The upper part of the vessel, which is the most vulnerable, inasmuch as the double hull principle terminates at the deck level, is protected by thin armour plate which is impervious to small-gun fire. The double hull also serves to protect the vessel to a certain degree against ramming and collision unless the impact be unduly severe. From time to time reports of successful ramming tactics have been made, but all such narratives must be regarded with suspicion. The rammer has expressed his conviction that his manœuvre

was successful from the fact that after the blow was delivered oil was observed to come to the surface of the water. Such a result, however, does not necessarily imply that the tactics were successful, since the oil fuel supply tanks are disposed in the space between the two hulls as described in the early part of this chapter, and as a reference to the diagram, Fig. 7, will reveal. The observation of air bubbles is more likely to be indicative of success, since these must be due to the entrance of water into a space containing air. Unless the fuel compartment pierced by the rammer happened to be empty, and the submarine navigator had been deprived of the opportunity to charge the space with water, the bubbles might arise from the piercing of the tank. Otherwise, it is fairly correct to assume that the inner hull was penetrated.

A great deal of public attention has been attracted during the war by the announcement that submarines built in German yards were dispatched across country to distant points such as Zeebrugge, Ostend, Antwerp and even to Turkey. By the Germania system of constructing these underwater craft in sections, this transportation is perfectly feasible, but such boats must necessarily be of small size and of limited radius of action, since, despite the fact that low trucks may be employed, transport is necessarily governed by the gauge of the railway track and the heights of tunnels and bridges.

CHAPTER XVI

OCEAN-GOING SUBMARINES

As the possibilities of the submarine became more and more obvious, it was inevitable that the idea of extending its sphere of utility should receive close attention. When it was first brought within the bounds of practicability, it was regarded essentially as an improved system for what might be described as local or coast defence. The original intention was to restrict it to home waters for the greater protection of the vulnerable points of a coast-line, ports, harbours and estuaries. Hitherto only the mine had been used for this purpose, but it was maintained that a submarine, with its torpedo armament, would be far more effective and formidable for such work.

In view of this prevailing impression, the early boats had a decidedly restricted radius of action, the cruising limits being about 300 miles. Several factors contributed to this state of affairs, the most important being the cramped quarters within the tiny vessel and the poor accommodation for the crew, combined with the circumstance that the boat could carry only two or three torpedoes. More-

over, at that time, the gasolene motors were far from being perfect: they had not established their ability to run smoothly and uninterruptedly for several hours at a stretch under full load. The liability of a serious breakdown of the cruising machinery, at such a distance from port as to prevent the return to the latter by the aid of the electrical propelling machinery, which had a radius of about 60 miles at 5 knots and which could be utilised for such a task in the event of an emergency, was considered too serious to be incurred. Wireless had not come into use as a means of communication between submarine and ship or shore, while there was considerable doubt as to how the tiny craft would behave in a sea-way.

As experience with the gasolene engines was accumulated, greater confidence became reposed therein, with the result that in 1903–4 the British and French Admiralties decided to construct boats having a radius of 1000 knots upon the surface. But even these vessels were intended for duty only within coastal waters. They were of relatively small dimensions, light displacement, and of low speed. The British boats had an over-all length of 100 feet, by 11½ feet beam, and a draught of 11½ feet, while they displaced 180 tons submerged. The speed upon the surface was 11 knots, and 7 knots when moving underwater. The French boats were larger and of higher speed. They dis-

placed 390 tons and could make another knot both when cruising and when submerged. But the increase of the radius of action in surface travelling was brought about solely for the purpose of enabling the boats to remain away from port for a longer period. It did not give them the capacity to venture farther out to sea or to undertake ocean cruises.

The engineers who have been responsible for the development of the submarine have ever been severely handicapped. They had no previous knowledge to guide them: they were, and still are, pioneers, and, as such, are compelled to discover things for themselves. In these circumstances they are forced to incur certain risks and to embark upon numerous experiments in the effort to widen their knowledge. Probably there is no other realm of human endeavour in which the truth of the old adage, "make haste slowly," has been brought home so forcefully as in the evolution of the submarine. The perfection of safe underwater navigation involved the encountering and mastery of problems more intricate than those in any other department of shipbuilding.

In the course of this progressive movement, and in view of the complete success which attended the perfection of the coastal defence submarine, the possibility of designing a vessel which could go farther afield, which could roam the ocean in abso-

lute safety, and which could participate in the tactics of the surface fleet, naturally claimed attention. But one point speedily became appreciated. A submarine for the latter duty demanded special design and construction, and the solution of further and more complex issues than had attended the perfection of the smaller coastal vessel. Another fact became apparent during the early stages of this latter investigation. The boats would have to be confined to one or other of the two distinctive duties: one boat of what may be termed a universal type would not suffice for both tasks. At the time this contention failed to be admitted by all those concerned in naval submarine science, with the result that a hybrid was produced, especially by the German Navy. As the war has proved, however, the tactical value of these craft is negligible. They are useful for commerce raiding operations and for corsair duties, but they cannot operate with a fleet.

To a certain extent the ocean-going submarine may be described as an enlarged version of its coastal defence prototype. Certainly it has been evolved from the latter, but there is a very marked difference in the external appearance and internal equipment of the two classes of craft. The ocean-going vessel has to encounter conditions which the coastal defence vessel never experiences, or can avoid, such as rough weather and heavy seas.

These boats are essentially fair-weather craft. Their hulls are of comparatively light construction, and are scarcely able to stand serious buffetings by

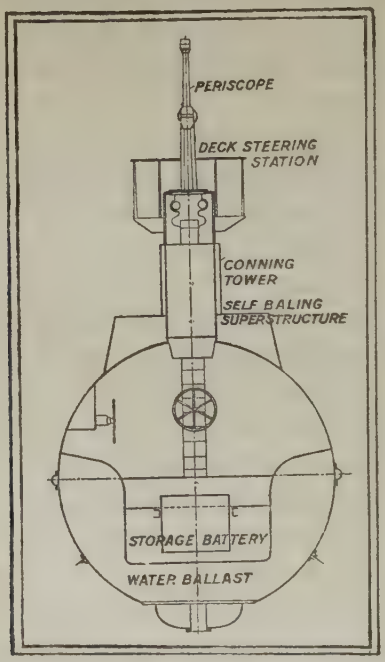


FIG. 8.—SECTIONAL VIEW THROUGH CONNING TOWER OF HOLLAND "PERFECTED" TYPE OF SUBMARINE, SHOWING CIRCULAR FORM OF HULL

the waves. They are indifferent sea-boats, rolling and pitching somewhat in a sea-way. True, the submarine by diving and travelling submerged can move in calm water and thereby escape all the evil

consequences prevailing upon the surface, but upon the ocean rough weather is liable to last for days, and a vessel can remain underwater for only a limited period, owing to the necessity to recharge the electric accumulators.

If a vessel of the coastal defence type ventures to sea for a long voyage, she must necessarily be attended by a parent surface ship to escort her through the journey. In a military zone, during war times, this might be rendered impracticable, inasmuch as the parent ship would become a conspicuous target for the enemy, and, if she were sent to the bottom, the safety of the vessel she was escorting would be seriously threatened. Of course, in such operations, both boats would be attended by destroyers or other war-vessels, but these would find it difficult to protect their charges in the event of an attack in force.

The ability of the submarine to cover long journeys under its own power was revealed by the *B11*, which sank the Turkish battleship *Messudiyeh* in the Dardanelles. The submarine travelled under her own effort from Portsmouth to the Eastern Mediterranean, but she had to be accompanied. Another remarkable journey of a similar character was that made by four submarines of the United States Navy, which, being obsolete for home service, were dispatched to the Philippine Islands, and made the long journey under their own power with an escort.

The super-submarine or ocean-going submarine must be independent of a tender or auxiliary. In other words, she must be capable of performing a specific duty, entailing a long voyage from home, and be sufficiently self-contained to sustain her

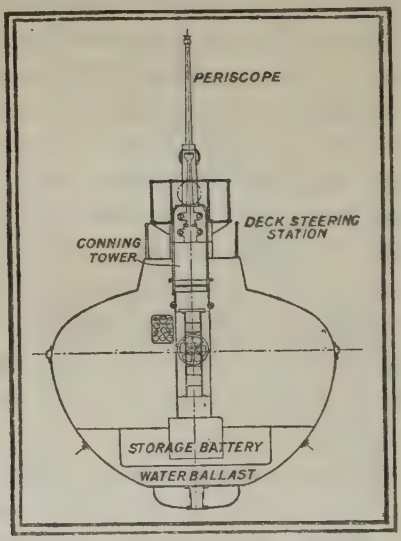


FIG. 9.—SECTIONAL VIEW THROUGH CONNING TOWER OF THE HOLLAND OCEAN-GOING SUBMARINE, SHOWING SPECIAL SHAPE OF HULL

crew for a prolonged period. She must act independently and be left to her own devices, relying upon communication with her home port, if required, by wireless relayed through intermediate ships, if the latter be available, or upon some other form of signalling. To be able to face any and every

kind of weather not only demands a hull of great strength, but one of special form. It was the decision to adapt the submarine to ocean-going duties that primarily brought about the German design of the double hull, the outer taking the form giving the greatest strength and the best sea-going qualities consistent with speed, while the inner hull, which carries the whole of the machinery, is cylindrical in section. The space between the two hulls is extensively subdivided into watertight compartments, a certain number of which must be destroyed before the buoyancy of the craft is sufficiently damaged as to cause her to founder.

The ocean-going submarine of to-day when compared with the puny vessel of fifteen years back conveys a graphic impression of the growth of the submarine and the relative rapidity of development. The American Hollands, which were the first British underwater craft, displaced 122 tons when submerged: the latest displace several hundred tons. The surface speed has been increased steadily and persistently; the radius of action has been extended from 300 to nearly 6000 miles, the latter at a reduced speed; while the underwater speed has advanced in a proportionate manner. Owing to the development of the heavy-oil engine, the horse-power per propeller shaft has risen from 160 to 2000 and 2,500. The first boats were driven by a single propeller, while those of to-day are propelled

by two or three screws. The electric propelling machinery has undergone a similar evolution, until to-day an aggregate of 2000–2,500 horse-power is available for propulsion underwater. Whereas the first vessel required a complement of seven officers and men for its operation, those of current construction require a crew of twenty-eight to forty officers and men working in watches. The pioneers could only travel at full speed underwater for four hours, but the latest ocean-going craft are able to cover from 140 to 160 miles at 5 knots, which means that they can move underwater for twenty-four to thirty-two hours continuously. The growth in dimensions is equally remarkable, the latest ocean-going vessels being more than twice the length of those of fifteen years back.

The French Navy is also being reinforced by some huge submarines. These craft are fitted with steam engines for surface propulsion, while the electric installation will give a high submerged speed. These vessels are designed to carry a crew of forty officers and men, and have a surface radius of several hundred miles at reduced speed. In the modern ocean-going submarine, the term " radius of action " is somewhat misleading, since it depends upon the extent to which the tanks carried in the space between the two hulls are devoted to the storage of the liquid fuel, while the rating does not necessarily imply " at full speed " but at that speed

which is the most economical in regard to fuel consumption. These divergent systems of rating have been responsible for considerable confusion in comparing the relative radii of action of different vessels.

The Italian Navy has also been strengthened by the addition of some large submarines of the F.I.A.T. type. They are submersibles of the type favoured by France, fitted with F.I.A.T. Diesel engines, developing 2000 to 2,500 horse-power per shaft. It is stated that these boats have a surface radius of action of 7000 miles and more, but this radius of action is based upon an average speed of only 8½ knots or less.

Although the United States, the home of the modern submarine, as it is known throughout the world to-day, followed a strictly conservative policy, it has by no means overlooked the advantages of the ocean-going vessel. The possibilities in this direction were revealed by the Holland boat *Salmon*, now known as the *D3*—the American Navy Department abandoned the policy of naming submarines, in favour of the system of numerals—which in 1910 made the over-seas voyage from Boston to the Bermudas and back, a distance of 1,500 miles, under her own power. This journey emphasised the safety and seaworthiness of these vessels under all weather conditions. It was this vessel which established the world's record for her

day, in regard to submerged speed, by making 12 knots on her official trials.

The Electric Boat Company, which holds the Holland patents, have also evolved a 950-ton ocean-going submarine, 212 feet in length by 21 feet beam, with a surface radius of 5000 miles, and a submerged radius of 140 miles. The engines for cruising develop 2000 horse-power. The armament is eight torpedo tubes, twelve torpedoes being carried. The complement comprise three officers and twenty-four men, while stores and supplies for thirty days are carried. The G class are among the most noteworthy at present in commission, the first of this class, *G1*, or *Seal*, of 540 tons submerged displacement, at the time she was commissioned, being the largest and fastest submarine in the United States Navy, and one of the most powerfully armed underwater fighting ships in the world. In addition to the usual fixed torpedo tubes in the bow of the vessel, the *G1* carries four torpedo tubes on top of her superstructure which may be trained independently; that is to say, the vessel herself when submerged does not need to be trained in firing as with the fixed tubes. During her trials the *G1* created considerable interest because in the submerging tests she descended to a depth exceeding 250 feet. She and two other boats of the same class are of the Lake type, and are virtually sister ships. These vessels have surface and sub-

merged speeds of 14 and 10 knots respectively, the radius of action being 1,200 miles. Three boats of the L class, numbered 5, 6 and 7, are also of the Lake type. In the general character of the hull they resemble the successful three boats of the G class, but many improvements have been incorporated in their design, operation and so forth. They displace about 600 tons submerged, and are driven upon the surface by Diesel two-cycle motors, and have a radius of action of 4,500 miles at 11 knots.

In the closing months of 1914, in view of the prominent part the submarine had played in naval operations during the opening phases of the war, the United States Government called for a number of submarines for harbour and coast defence, as well as for one ocean-going "fleet" vessel. The Lake Torpedo Company, in tendering, submitted plans for a vessel to comply with the last-named requirement, displacing 925 tons upon the surface.

It is somewhat strange that the United States has not played a more prominent part in the encouragement of submarine boat construction. Whereas other powers are able to obtain delivery of the latest and most powerful types of vessels within a few months, in America about four years elapses between the signing of the contract and the preliminary acceptance of the vessel by the authorities. The contract for the *G1* was signed

on February 3, 1908, but she was not taken over until October 18, 1912. Thus the building of this vessel occupied more than fifty-six months. In view of the rapid strides that are being made in submarine naval science and engineering, such a state of affairs is little short of calamitous, since an American boat is virtually obsolete before she is completed, or, at any rate, may be hopelessly superseded in practical value by the vessels of other powers. Recently there has been a noticeable speeding-up in submarine construction, but whether it will be maintained remains to be seen. But the fact is only too apparent that in matters relating to underwater fighting ships the hustling Republic is eclipsed by the European nations.

The submarine fleet which is most regarded with awe by the general public is that of Germany. The Admiralty of that country, as if realising the approaching dawn of " The Day," veiled its submarine developments with complete secrecy and mystery. According to the reports which were diligently circulated, and apparently with official approval, if not by instigation, the latest German submarines were to startle and to lead the world in this branch of naval engineering. Certainly their achievements during the opening stages of the war appeared to lend substance to rumours, while the successes accomplished upon the declaration of the notorious blockade tended to convince the incredulous. The

German craft became invested with extraordinary super-submarine powers.

Popular credulity and rumour are not, however, substantially supported by facts. The great majority of the submarines which Germany possessed upon the outbreak of war were of a small type, similar to the two craft which were delivered to the Austro-Hungarian Navy preceding the outbreak of hostilities. These vessels have an over-all length of 142 feet, a beam of 12 feet 4 inches, and a surface draught of 9 feet 8 inches, displacing 300 tons submerged. They are of the same structural design as the larger craft, being fitted with double hull and watertight subdivision of the intervening space, with the capacity to utilise a certain proportion of this space for the storage of the liquid fuel. Surface navigation is accomplished by two-cycle heavy-oil engines, developing 600 horse-power, capable of giving a surface speed of 12 knots, while the electric machinery, developing 320 horse-power, supplies a submerged speed of 9 knots. The Krupp company has specialised in these small craft, a number of which were on the stocks for various Powers when war was declared. These were taken over by the German authorities. At 10 knots speed the radius of action is about 1,600 miles, but by travelling at a reduced speed of 8 knots and by impressing additional watertight compartments into extra reservoirs for liquid fuel, it has been found

possible to extend the radius of action to nearly 3000 miles. These were the craft which harassed British commerce in the North Sea and the English Channel, until the passage of the Straits of Dover was rendered impossible. These vessels are well adapted to sea-going duties, since they are fitted with sleeping accommodation for the crew.

The newspapers have lately been filled with sensational reports concerning mammoth German submarines, but a consideration of the fact will show that the greater part of the work of the blockade was performed by these long-travelling mosquito craft. Time after time exciting escapes of vessels were narrated. Yet the majority of these boats which succeeded in showing their underwater foes a clean screw and rudder were of low speed and certainly could not notch more than 16 knots, even when steam was crowded on and they were driven at their hardest; while in many instances the escaping craft could not attain a speed of more than 14 knots. If the submarines had been possessed of the surface speed with which they were credited, namely, 17 knots, not one of these freighters could have got away: they must have fallen victims to superior speed.

It is true that contemporaneously with the construction of the foregoing craft, submarines of 500 and from 750 to 800 tons displacement when submerged were undertaken; but it is quite safe to

assert that no larger craft were in commission during the first ten months of the war. The 1000-tonner of 20 knots surface speed, about which so much had been written, apparently existed only in the imagination of the inspired German press agencies. The 800-ton boats have a speed of 16 knots upon the surface. In the course of a description, written by a German naval officer who was present at the official trials, it is stated that *U47*, of 800 tons, one of the latest vessels, cruising at a speed of 8 knots has a fuel consumption of 10 tons of oil fuel per 1000 miles, and normally carries 50 tons of liquid fuel, which gives a radius of action of 5000 miles. But it will be observed that the economical cruising speed is set somewhat low for a vessel which is supposed to be of high speed. From this statement it is only logical to assume that the maximum surface speed of the vessels does not exceed if it attains 16 knots. The German submarine builders, in common with the designers of Great Britain, France, Italy and the United States, are fully aware of the great problems which have to be overcome before the 1000-tonner 20-knot submarine can be launched; and, owing to the condition of affairs at the moment, the men who first achieve this goal are scarcely likely to communicate the fruits of their experiments and investigations to their deadliest rivals.

The fact that the German fleet possesses sub-

marines having a cruising radius exceeding 3,500 miles has been conclusively established. The German vessel which torpedoed the British warships *Triumph* and *Majestic* proceeded from Wilhelmshaven to the Eastern Mediterranean under her own power. It is somewhat doubtful whether the journey was accomplished without a replenishment of the fuel bunkers, inasmuch as a warning was issued by the British authorities some days before the vessel made her presence so effectively felt. Seeing that the submarine would have been particularly anxious to gain the waters around her destination in secret so as to become a veritable "cat among the pigeons in the Dardanelles," it is logical to assume that she put into some secret base to take on fresh supplies.

"But," one may ask, "how can a submarine be absent from port for a month on end? How about provisions?" This question, which appears at first to present an insuperable difficulty, is one of the simplest. The advances in the science and commercial practicability of storing and preserving foodstuffs have overcome this obstacle. The provision of ample supplies of food, drinking water, and air does not occasion the slightest anxiety. Indeed, if the emergency arose, the submarine could take on board adequate supplies for an absence of three months.

CHAPTER XVII

HOW THE SUBMARINE MAINTAINS COMMUNICATION

SEEING that the German submarine has played such a prominent part in what may be described as corsair operations, a popular curiosity prevails as to how these vessels are enabled to communicate with the Vaterland or with one another, either when travelling awash or submerged. The German underwater fighting ships, in their raids upon British commerce and outlying naval units, have been compelled to proceed unaccompanied to waters several hundred miles away from Wilhelmshaven, and have been absent for a month or more. In certain instances nothing has been heard of a submarine during the period she has been at sea. If she does not return within a specified period her loss is presumed. Upon other occasions the German headquarters have gleaned intelligence of a coup from a point some 500 or more miles away, and that within a very short time after the event. For instance, the British battleship *Formidable* was sunk some distance down the English Channel, but the German Admiralty was speedily in possession of full details concerning the incident.

In this instance, the apparently impossible may be easily explained. At that time the English Channel was receiving exceptional attention from the German underwater craft. The boats concerned were fitted with wireless telegraphy which at night have an effective radius of about 150 miles. The battleship was sunk after dark and the welcome news was flashed—in code—from the successful submarine, to be caught by the submarine operating farther east, by which the message was relayed to a third vessel, and again relayed to a shore station on the coast of Flanders, probably Ostend, whence it was finally transmitted to Berlin.

The British Navy was the first to equip the submarine with wireless telegraphy, and, after considerable experiments, it was found possible to communicate therewith over a distance of about 120 miles during the day, and from 150 to 180 miles during the night, the radius varying according to climatic conditions.

Wireless telegraphy, although the most satisfactory means of communication, and that having the greatest radius, is not the only signalling system possible with the submarine. When travelling awash the submarine is like any ordinary surface craft, and can employ the conventional methods of signalling. Under daylight conditions these may be shape signals, flag signals, the wig-wag, or semaphore. By night, Véry's lights, the wig-wag

torch, and the searchlight are possible, the latter sometimes being used during the daytime.

There are other methods of conveying signals either by day or night and with the boat awash or submerged. Some years ago, long before the submarine had come to be regarded as a permanent factor in war fleets, a system of communication by wireless telegraphy, which could be applied to submarines, had been brought to the practical stage. In this instance aerial masts were not employed, the earth, or rather the water, instead of the air, being used as the conductor. The antennæ were immersed. A low-tension system was used in conjunction with an electro-capillary relay of extreme sensitiveness. The system proved completely successful, though at that time it was being exploited for a totally different marine purpose. So far as submarines were concerned it was premature, since the underwater fighting ship was in its infancy and had given no indications of the revolution it was destined to effect in naval circles.

Shortly before the outbreak of war the system was revived, with improved apparatus, the necessity of conversing with submarines when travelling submerged having become appreciated. The aim of the experiments was essentially to provide a vehicle of communication between two submerged submarines, between a submerged submarine and a friendly surface warship, or between a sub-

merged submarine and a shore station. The perfection of the process will completely revolutionise radio-telegraphic communication so far as it concerns submarines. Even when the boats are travelling awash it will be applicable and invaluable because it will dispense with the aerial.

But the system of submarine communication which has proved the most successful up to the moment is the submarine bell. This signalling process has been brought to a high standard of perfection, and has been employed upon liners and warships for many years past. If a bell be immersed in one end of a tank of water, and in the opposite end of the tank be submerged a sensitive microphone, when the bell is struck the sound will be distinctly audible in the microphone. This is the simple principle of the bell-signalling system, and success is due to the fact that sound travels through water four times as rapidly as through the air—4,700 feet per second as compared with 1,070 feet per second.

The modern submarine carries a submarine bell, operated by electricity, as well as receivers for receiving the bell signals. The receivers are special microphones immersed in certain solutions stowed in a box and attached to the hull of the vessel. Two microphones are necessary, one on the port and the other on the starboard side respectively, and they must be placed in such a position that they

are under water even when the boat is travelling in the light condition. Wires extend from each microphone to an ordinary telephone receiver.

Two ear receivers are advisable in order to determine the direction from which the sound is proceeding. If it is upon the port side the sound in the receiver connected to the port microphone will be louder than that in the starboard receiver. If the sounds are of equal intensity, then it proves that the submarine is driving directly towards the point from which the bell sounds are being given. The arrangement of the microphones is such that all other sounds beyond the bell, including the ship's noises, that is the sounds produced upon the vessel herself, are eliminated.

Unfortunately the submarine bell has severe limitations. Under the most favourable conditions signals may be exchanged with fair reliability and absence of confusion up to about 10 miles, but if the conditions are adverse 800 yards will probably represent the limit of conversation. So far as the submarine is concerned, the receivers are turned to additional account. If the submarine wishes to come to the surface she first desires to ascertain whether there are any surface vessels in the vicinity. All machinery is stopped and amid the intense silence which prevails the operator listens attentively. If a surface craft be near the noise of her propellers revolving in the water will be heard.

The microphone may also be utilised by a surface vessel as a means of determining whether or no a submarine is lurking in the vicinity of a suspected spot. If one take an empty tin, places therein a mechanical musical toy which is set going, seals the tin and lowers it into a tank of water, then at the opposite end of the tank introduces a microphone, the sound from the musical toy will be plainly heard in the microphone. At sea the submarine is like the musical box, the hull forming the containing vessel, while the drone of the electric motors corresponds to the tune which is emitted. Curiously enough, the sound produced by the motors does not seem unduly loud to those within the submarine, but to the listener with the microphone it is very distinct. Moreover, the droning of the motors is associated with the noise produced by the revolving propellers. The serviceability of such a system of determining the whereabouts of a submarine is dependent upon the sensitive character of the microphone. The listener has one great advantage. A submarine running at a depth of some 40 feet or so is moving in a silent world; there are no extraneous noises which may lead to confusion or obliteration of the sounds; they are quite clear.

An interesting application of bell-signalling to submarine operations was revealed during the progress of the American naval manœuvres a year or two since. A surface craft was being followed

by two submarines, but the latter were travelling at different depths. The one vessel was submerged to a depth of 15 feet, while her consort travelled at depths varying between 70 and 100 feet. Both vessels ran at a speed of $7\frac{1}{2}$ knots per hour. The lower vessel was directed entirely by the upper vessel, the latter conveying her instructions to her consort by means of submarine bell signals. For two hours these two vessels continued running in this manner, and then, when the lower vessel was instructed to rise to the surface, she came up at the spot desired. This control of the movements of one submarine by another submarine is somewhat novel, and opens up new possibilities in submarine attack. In such tactics the upper vessel might meet with disaster, but owing to her guidance of the sister ship, the latter might be enabled to take a speedy and deadly revenge. Under certain conditions the sacrifice of a submarine might prove indirectly fruitful; at all events, if the upper vessel executed a movement to ensure her safety she might act somewhat in the nature of a decoy, thereby attracting the hostile surface vessel's attention while the second and unsuspected submarine thrust home her attack.

Sound signalling is capable of considerable development, and in this field of scientific research and investigation inventors are particularly active. The United States Navy has been using what is described

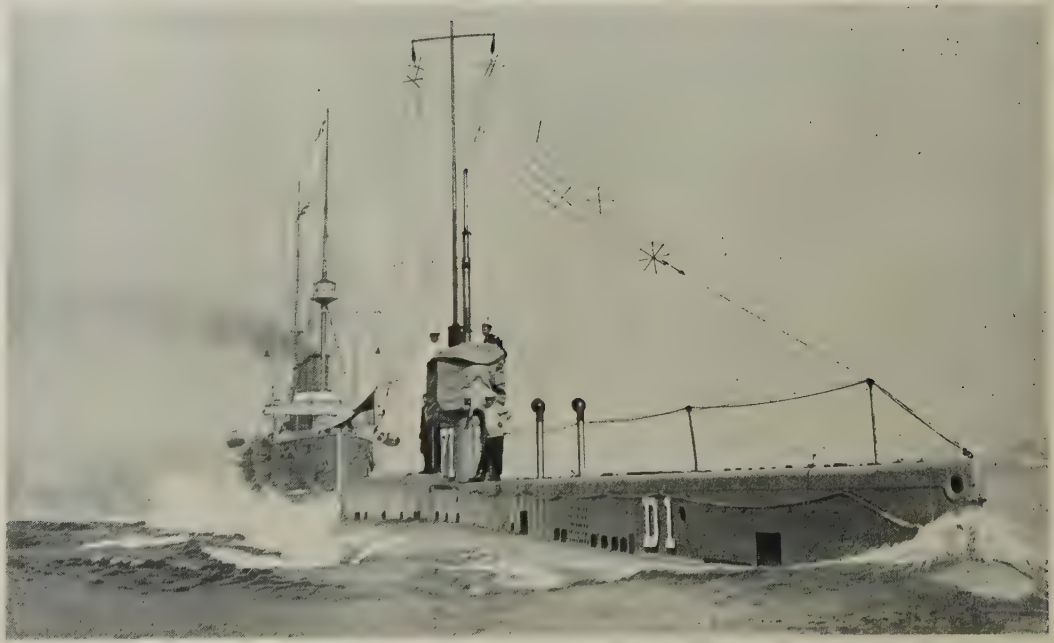
as a "submarine violin" to this end. It is the invention of an Austrian who, when he submitted it to the Austro-Hungarian Government, met with scant encouragement. Thereupon the inventor sailed for the United States, where he had a more friendly reception. The idea is applicable for communication between submarine and submarine, or other craft, as well as between submarine and shore. Two projections are attached to the hull of the submarine and between these a piano wire is stretched taut. Outside the submarine a wheel with a roughened rim is mounted, the shaft of which extending through the plating to the interior of the vessel, is coupled to an electric motor. This wheel is so mounted that the irregular edge of the rim comes into contact with the taut wire. The motor within the submarine is controlled by a Morse key, the wheel being set in motion and continuing to revolve while the key is depressed. By interrupting the revolution of the wheel, in accordance with the dots and dashes of the Morse code, messages may be sent at the rate of about eight words per minute. The receiver is an ordinary microphone which is lowered into the water. Since the submarine acts as a sounding-board, the sounds impelled through the water by the wheel-rim scraping the wire are somewhat intense, and have been picked up at a range of five miles or more.

Recently another invention has claimed world-

[*Cribb*

ONE OF THE LATEST BRITISH OCEAN-GOING SUBMARINES

Comparison with the "Baby Holland" (facing page 38) conveys a striking impression of the development of the underwater fighting ship in the British Navy.



[*Cribb*

British Submarine *D1* with her Wireless Rigged

The aerial can be speedily dismantled preparatory to submergence.

wide attention. This is known as the Fessenden oscillator, which is an improvement upon the submarine bell. In place of the latter instrument a large steel disc is set in position upon the outer surface of the ship's hull and connected with further apparatus attached to the inner side of the vessel. This disc is actually a huge diaphragm, which is free to vibrate, its oscillations being controlled by an electric current. The vibrations are capable of extensive variation so that the pitch of the sound emitted may be altered within wide limits. When it vibrates slowly, the sound is deep and sonorous, but with rapid movement a high-pitched, shrieking note is produced.

Will any signalling device applicable to submarines come into general use? This is an obvious question, but one which is not so readily answered. At first thought one might feel that the Powers would be only too quick to adopt a proved principle of maintaining communication through the water, so as to keep in touch with the submarine throughout its movements and during its absence from port. By such means it would be possible to dispose the units of an underwater flotilla to tactical advantage.

But a little reflection will show that the inauguration of any signalling device of this character is destined to rob the submarine of its potency and one of its finest attributes. It is able to profit from its invisibility which, in conjunction with its ability

to maintain silence during its operations, has rendered it a decidedly deadly menace. But if a signalling system is to constitute an essential part of its equipment it will be robbed of a great deal of its terror. Nothing will betray a submarine's existence or whereabouts so completely as any method of audible signalling. The sounds can be picked up by friend and foe alike. True, messages could be sent in code and might baffle deciphering, but that would be a mere detail, because the receipt of a code message would put a hostile submarine or other warship within range on the alert. The suspicion that a submarine might be lurking in certain waters would be converted into an absolute certainty by its conversation through the water, and it would not be a matter of any difficulty to calculate the radius in which it was lying in wait. This lack of secrecy in communication is the weakest feature of underwater signalling methods so far as submarines are concerned, because, as war has proved, the power of the submarine lies in its ability to strike hard, quickly and accurately in waters where its presence is unsuspected.

CHAPTER XVIII

COMBATING THE SUBMARINE

Is the underwater fighting ship invincible? This has been an ever-recurring question since the day when the German Government declared the "piratical blockade" of Great Britain, which, interpreted, signified the sinking of all shipping on sight. It must be conceded that the Teuton assassins of the sea reaped a rich harvest among the mercantile marine, although the prizes as a rule were the small fry, of low speed, and for the most part complying with the designation of "tramps." By a strange irony of fate, owing to the remorseless manner in which the submarine campaign was waged, it was neutrals, as much as Great Britain herself, who suffered from the notorious edict.

A harvest was only to be expected, because, from the day the gauntlet was thrown down, British shipping continued the even tenor of its way, while when one bears in mind the somewhat dense character of the sea-going traffic in the waters washing the British Isles it would have been next to impossible for the Teuton undersea fleet to have failed to place certain achievements to its credit. From the mili-

tary point of view the significance of the results was disappointing; the German submarines failed lamentably to exercise any influence upon the progress of the war. British transports plied the English Channel as serenely as if the submarine still remained a dream unfulfilled. Strive how they would, and their ingenuity and perseverance in this direction were astonishing and unceasing, the Teuton submarines could not plant a torpedo in the hull of a vessel carrying troops or supplies in British waters, although they were more successful in the Ægean Sea and Dardanelles.

But although the German submarines were making merry among the tramps and trawlers, the British Admiralty was far from sleeping. As might have been anticipated, the authorities were inundated with ideas, inventions and proposals for locating and destroying hostile submarines, but the majority were wildly impracticable. One or two schemes were submitted to the stern test of practical application, but were not entirely successful.

The old saw advises that a " thief should be set to catch a thief," but a submarine cannot be set to catch a submarine. They cannot fight one another, except, perhaps, in the event of two hostile vessels rising to the surface simultaneously and trying conclusions with their respective guns. A combat of this character has not been recorded, and it is extremely doubtful whether the war will provide a single instance of such a conflict. One or two

vessels have been engaged in novel duels and have triumphed over their adversaries, but these are unusual episodes, and not likely to be repeated, except at rare intervals.

Can a submarine be trapped? If so, how? Can it be mined, or can it be caught "alive"?

The possibility of destroying a submarine by a mine is extremely remote. Mines are planted in the fairways and certain reaches of water in such a manner as to imperil the passage of surface craft. They lurk from 10 to 15 or 20 feet below the surface, being held in position by anchoring cables, and, fouling the unsuspecting passing vessel, are detonated by the ship herself. But the submarine is not likely to strike these obstacles. If the underwater vessel be travelling awash her draught is so slight as to carry her well above them, while if moving submerged she is likely to pass beneath them. The only mine menace to the submarine is the floating type, but in this instance destruction is due entirely to luck and not to judgment.

Even should a submarine foul an anchored mine, it does not necessarily follow that the latter will be fired. It will be remembered that in the Dardanelles a British submarine's propeller became entangled with the anchoring cable of a mine. The craft came to the surface and there was the mine in tow. Although there was imminent danger of an explosion, the crew unconcernedly set about cutting the dangerous obstruction adrift, in which task they finally

succeeded, crowning this apparently impossible achievement by destroying the peril.

When the submarine first made its appearance it was considered possible to compass its destruction by means of the spar torpedo, and a device to this end was contrived and tested. The boom, when extended, enabled the torpedo to be exploded about forty feet from the side of the vessel engaged in the work. The procedure was simple. Upon a submarine, for the appearance of which the torpedo-boat maintained a keen vigil, coming to the surface, the destroyer was to steam up to the spot at full speed and to explode the projecting charge either against the underwater boat's hull or in close proximity thereto. In those days the hull of the submarine was a mere eggshell, and it was maintained that the concussion arising from the explosion would either stave in the plates or impart such a tremendous disturbance as to upset the submarine's somewhat delicate equilibrium, thereby causing her to founder.

A modification of this principle constituted the firing of mines close to the submarine, and some years ago one of the five Hollands built for the British Navy was sacrificed in an experiment to test the possibilities of this idea. So far as they went they were satisfactory, because, in those days, the underwater vessels were decidedly frail in construction; but the increasing strength of the hull, as well as the development in speed and quick

diving properties, somewhat nullified this practice or, at all events, rendered it uncertain. Consequently the practice fell into disfavour for a time.

A new type of spar torpedo was evolved and tested, but it was found that the vessel which was appointed to this peculiar duty was exposed to serious danger. The rigging-up and dismantling operations occupied appreciable time, while during this operation the vessel had to be stationary. In this condition she was helpless, and constituted an excellent target for a hostile submarine, which stealthily approaching the destroyer, might be able to launch a torpedo which would either inflict serious damage upon the surface vessel or send her to the bottom.

Dragging with semi-floating mines was another idea which has been submitted to test. In this instance, two vessels, travelling side by side but a certain distance apart, were attached by a main cable. The latter, in turn, was connected to a number of short lateral cables, to the free end of which small mines were attached. The mines were of special design and charged with high explosive, such as gun-cotton or trinitrotoluene. They were of the controlled type, *i. e.* electrically detonated. By attaching the mines in this manner to short lateral cables they were allowed a certain swinging movement. As the main cable was dragged through the water the mines themselves swung hither and thither, the degree of this movement varying accord-

ing to the speed of the vessels. In the event of a mine, with its attached cable, coming into contact with a submerged obstruction, such as the periscope and top hamper of a submarine, these projections were likely to be fouled and the fact to be communicated to the two towing vessels by a sudden tension upon the main cable. The mine was then to be fired electrically, being accompanied, if required, by the mines immediately on either side of that which had dragged the obstruction. A high explosive charge was not necessary, for the simple reason that a comparatively slight explosion would serve to rip the hull of a submarine sufficiently to jeopardise her safety. This practice was likewise abandoned, since it was impossible for the towing vessels to move at high speed owing to the fact that the sag or submerged depth of the cable and mines was so slight that it might easily pass over a submarine. Furthermore, the scheme was nullified by the double-hull system of construction which has come into vogue in submarine design: the outer shell might be damaged, but that would not necessarily imperil the vessel.

In the early days, when submarines were small, "netting" was practised. Admiral Sir A. K. Wilson was responsible for the production of a large steel net to achieve this purpose. It was successful to a distinct degree, but, as boats were increased in size, displacement and power, the difficulties attending the netting idea assumed complex proportions.

Two of the most positive means of putting a submarine out of action are ramming and gun-fire. The majority of destroyed vessels have been sent to the bottom by the former method. The destroyer, or light cruiser, from its high travelling speed, is peculiarly suited to this duty. For instance, should a submarine be surprised by a destroyer travelling at, say, 25 knots, the chances of escape are extremely slender. A speed of 25 knots represents 43 feet per second. Assuming that the surprised submarine, travelling light, immediately commenced to dive, three minutes at least would elapse before she had attained the safe submerged condition. During this period the destroyer, travelling at 25 knots, would cover 7000 feet—practically $1\frac{1}{3}$ miles—so that the submarine would be doomed.

It will be remembered that a speedy destroyer also accounted for a German *unterseeboote*. Here again it was ramming which was responsible for the deed. This episode, however, was somewhat romantic and certainly sensational. The German submarine was travelling light, and in the intense darkness did not descry the destroyer, which was travelling at top speed, until escape was hopeless. In fact, the commander of the German submarine appears to have lost his head; to have been paralysed at the cliff of steel rearing above him. The destroyer's stem caught the submarine near the conning tower. The impact carried the submarine, impaled on the destroyer's stem, forward some dis-

tance, and then slewed her round as if on a pivot until she lay immediately alongside, her bow facing the destroyer's stern. The two boats were so close together as to preclude the possibility of raking the submarine with gun-fire, because the destroyer could not depress her gun sufficiently. The destroyer's consort was equally helpless. She could not let fly with her guns for fear of hitting her sister-ship. It was a weird, nerve-racking situation in the ghostly rays of the searchlight. Rammer and rammed could do nothing : one was compelled to watch the other. The captain of the submarine, as soon as he gathered his dazed senses, failed to realise the fact that the hull of his vessel was ripped and that water was pouring into her, and instinctively commenced to dive. The illumination within the submarine was plainly visible to the destroyer's crew as it shone through the ragged rent in the vessel. The incident was soon over. The water rushed into the battered underwater boat and she disappeared from sight. The German Admiralty subsequently announced that the rammed submarine reached port safely, but the report is generally discredited.

Ramming and rapid gun-fire so far have proved to be the most reliable means of sending a submarine to Davy Jones' locker, and, all things considered, the first-named procedure is the one upon which the greatest dependence can be placed. But the submarine holds the superior position. Unless the captain of the underwater craft is abnormally daring,

or considers himself to be absolutely safe, although moving in a dangerous zone, he will not permit more than his periscope to project above the water during the hours of daylight. If all is clear within the radius of vision he can come to the surface, but not otherwise. The periscope is an insignificant target at which to take aim, and it is not likely that it can be struck at a range of 3 miles.

In view of the enormous advantage held by the submarine, one is prompted to ask how the whereabouts of a submarine may be detected. Experience has proved that spotting from aloft is the most reliable means of consummating this end. The whereabouts and movements of a submarine are plainly discernible to an aeroplane or dirigible: the outline and details of the submerged vessel are as distinct and defined at a depth of 40 feet as if she were travelling awash.

This ability to see into water may easily be proved. If one be fishing beside a stream and the water is clear, one cannot see the bottom. But pass to a bridge near by, and peer vertically downwards. The bottom is quite distinct, while movements of fish may even be discerned. It is the same with the vessel of the air. The observer looking directly downwards can see the sea-bed and all that moves over it up to certain depths, the underwater visibility increasing as the vessel rises higher in the air (Fig. 10). It will be remembered that when Bleriot flew the Channel, he related how upon his approach

to the British coast he had distinguished British submarines travelling submerged. But sighting must be vertical, and the area of the sea-bed rendered visible is confined to a comparatively slight angle on all sides of the 90 degrees. When one looks obliquely into the water the line of sight is bent sharply, an effect due to refraction. But the conditions must be extremely favourable. Factors of light, weather and turbidity or clarity of the water affect the issue very materially.

When the submarine is pitted against aircraft it suffers from an extremely serious disadvantage. It may not even be aware of the fact that it is being watched as it sweeps the horizon with its periscope. If the flying machine maintains a position immediately above the submarine it cannot be detected by the latter, since the periscope is designed for sighting only in the horizontal plane : it cannot see directly overhead.

It is a striking example of the stalker being stalked, and if the aircraft be armed there is every possibility of the submarine being destroyed. The overhead enemy can descend to a low altitude, and by keeping pace with the submarine can remain poised immediately above the latter, watching and waiting for the moment when the submarine, feeling assured of safety, thrusts its deck above the water, when the aerial vessel may launch its bomb or other projectile. If the missile is fired, instead of being dropped—that is to say, if it is given an initial velocity and is well

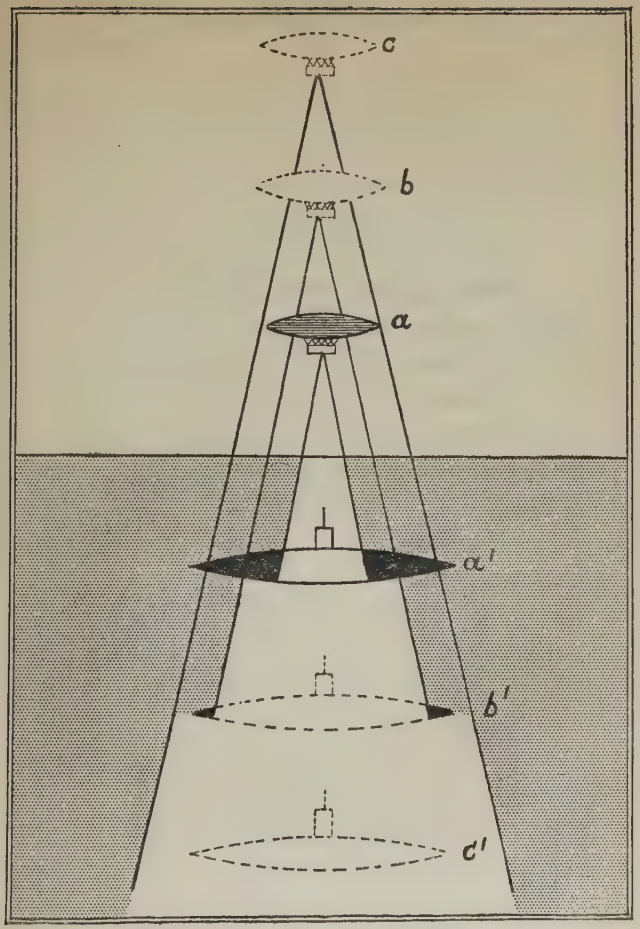


FIG. 10.—SPOTTING A SUBMARINE FROM ALOFT.

As the aeronaut rises he is able to see more deeply into the water, while the field of vision is widened. When the airship is at a less than half of the submarine at a^1 may be seen. When the aerial vessel rises to b nearly the whole of the submarine at b^1 may be visible, while the airship at c may see the whole of the submarine at c^1. The black areas represent the invisible sections of the submarine at the relative positions.

and truly aimed, instead of depending upon the force of gravity for its momentum—the chances are that the submarine will be hit.

The most striking demonstration of the ability to destroy a submarine from the air was afforded by a British aviator. He spotted the hostile craft and at a favourable moment released his projectile, which, striking the submarine fairly and squarely, rent her hull in all directions to such an extent as to precipitate almost instantaneous foundering.

In operations of this character the dirigible—a small one for preference—is preferable, for the simple reason that it has the advantage of speed range and the capacity to hover. The underwater speed of a submarine is far too low to enable an aeroplane to maintain a position directly overhead. The maximum submerged speed of the latest submarines is about 12 knots, though, when cruising submerged, the speed falls to 5 or 6 knots. This is a speed to which the aeroplane, as at present constructed, cannot be reduced.

The submerged speed of the submarine is excellent for the dirigible, which can hover or vary its altitude easily and readily without resort to hard climbing or planing movements. Once the submarine has been picked up by the dirigible, the latter can descend as near as 100 feet above the water, and remain hovering at that height until the submarine emerges for a breather or to take stock of the situation.

The airship has been stated to possess little or no conspicuous military application, but there is every indication that it will become indispensable in spotting and tracking the submarine. It can follow every movement of the latter and defy all attempts at escape. If the airship be fitted with wireless it can render the stalking operations of the submarine absolutely valueless. It can warn passing vessels and can keep in touch with the destroyer patrol in such a way that the latter are able to lie just beyond the periscope's range of visibility, and at the critical moment can even guide the destroyers in a successful attack.

Of course airship tracking is impossible during the hours of darkness, but, fortunately, the submarine is no better off under such conditions. At night it is as blind as a bat, and the periscope is useless. Its great asset of invisibility is stated to shake the *morale* of the crews of surface travelling vessels; but it is certain that nothing undermines the *morale* of the submarine's crew so effectively as the "assassin of the air." It must be remembered that the nerves of those who man the underwater fighting ships are strung to the highest tension. They dread nothing so terribly as the peril from the air. It is one against which they have no means of protecting themselves, and this extra strain on their nervous system, when pushed home sufficiently hard, is likely to bring about a complete collapse. All things considered, it may be

accepted that the dirigible, and even the aeroplane, when the problem of imparting a hovering capacity to this machine has been solved, is the natural predatory foe to the submarine.

This ability to distinguish a submerged submarine from the air has exercised a distinct influence in another direction. The patrolling of submarine infested waters by surface vessels is a wearisome and, to a certain degree, racking duty. There is that feeling of perilous uncertainty which always prevails when one is searching for a foe who has the advantage of being under cover, and who is lurking for the first favourable opportunity to strike; who is taking full stock of your movements but who cannot be seen. In this particular work the men have learned to observe slight movements and slender indications which under normal conditions would not occasion a second thought. The actions of the sea-birds in particular are followed with the closest concern. They will follow a submarine relentlessly and expectantly, shrieking and wheeling, as it varies its submerged movements. The birds can see the submarine quite distinctly, and it is almost impossible to distract them or to induce them to abandon the strange pursuit. Thus their line of flight offers a clue to the direction in which the submarine is heading, and the patrolling vessel, by watching the water closely, can generally succeed in picking up the periscope when it is lifted above the water to take a peep.

CHAPTER XIX

THE SUBMARINE FLEETS OF THE WORLD

WHAT was the situation of the various belligerents upon the declaration of war, in regard to the numerical and fighting strength of the individual underwater fleets? This affords an interesting study, although it is one upon which it is difficult to express a definite opinion for the significant reason that, some two or three years previous to the outbreak of hostilities, the prospective antagonists, as if anticipating the conflict, decided to prosecute all activity in this field behind drawn curtains.

So far as Great Britain is concerned she easily led the way in point of number of vessels and fighting efficiency, despite the fact that she accepted the principle of underwater fighting some years after the French nation. Whether the policy was correct or otherwise, since Great Britain was in the position to assert and to hold the command of the sea, it was decided to embark upon a comprehensive submarine building programme, and to pursue it as energetically as the new naval science would permit.

The inevitable happened. Accidents overtook the investigations, and it appeared as if the sub-

marine could not possibly develop into a serviceable and reliable unit. But disasters are inseparable from pioneering, especially in such a realm as this; and the only consolation is that they are productive of valuable lessons which, if properly and thoroughly taken to heart, result in ultimate triumph. The A class was speedily improved out of all recognition. Many lessons pertaining to the propelling machinery were learned, and two notable points were emphasised. One was the possibility of using a heavy-oil engine for surface propulsion in preference to the more popular gasolene motor and its inflammable fuel. *A13* was designed to use heavy oil, and, though the engine of the period was full of imperfections, there was every indication that this class of motor constituted the ideal prime mover for submarines when travelling upon the surface. The second point which was driven home was the possibility of adapting the submarine to ocean-going duty. This was primarily a question of storing the oil on board, and *A13* was provided with facilities for carrying 13 tons of liquid fuel.

The A class was succeeded by an improved and larger type of vessel, known as the B class. In these craft, the improvements suggested as a result of experience with the previous class were duly incorporated, the submerged displacement being increased by 50 per cent., from 204 to 313 tons, while

speed and radius of action were improved to 13 knots and 1,500 miles respectively. The boats of the B class were efficient fighting ships and possessed sea-going qualities. Although from eight to eleven years old, they still possess a distinct fighting value, as was proved by the exploit of *B11*, the last of the class to be built, in the Dardanelles.

Improvements were still in progress and were embodied in the C class, of which, altogether, thirty-seven vessels were constructed. This class may be said to constitute the actual foundation upon which the British submarine fleet of to-day has been built, for the craft of successive classes are really improved "C's." The latter were of the same dimensions, displacement and horse-power as their immediate predecessors, the first eighteen vessels having a length of 135 feet, by 13½ feet beam, a draught of 11½ feet, and a radius of 1,500 miles. The second nineteen vessels of this class, however, were given an increased radius of action—2000 miles.

The D class comprised boats of much greater dimensions and displacement, the radius of action being increased to 4000 miles, while the gasolene motor gave way definitely in these boats to the Diesel heavy-oil engine. The *D1* marked an important departure, as recorded in a previous chapter, inasmuch as she carried a light quick-firing gun. Then came the E type, followed ultimately in 1913 by the F and other classes, which are among the

largest and most powerful submarines ever constructed.

All these various classes are founded upon one model—that developed by the Government and Messrs. Vickers conjointly. In 1913 it was decided to introduce other types into the British Navy. The Laubeuf submersible, which had achieved such distinct successes in the French Navy, was taken in hand by the famous Elswick armament firm, Sir W. G. Armstrong, Whitworth & Co., Limited, while a Clyde firm of shipbuilders, Messrs. Scott & Co., Limited, had acquired the licence to build the F.I.A.T. Laurenti submarine, which is the finest type of submarine in the Italian Navy. A number of vessels of these two distinctive types were ordered as well as several of what were distinctively named the "Vickers Special." In addition, two vessels of 2,500 horse-power, acknowledged as ocean-going or "fleet" submarines, were put in hand. Curiously enough, in the case of these two boats the British Admiralty made an interesting departure from prevailing practice. Hitherto the British submarines had been divided into classes, taking letters of the alphabet in regular sequence, while the boats of each class were numbered consecutively from one upwards. But in the case of the "fleet" submarines, they were christened *Swordfish* and *Nautilus* respectively.

When war was declared, the British submarine

fleet comprised seventy-two vessels, the oldest of which, *A5*, was built in 1904. But even the oldest vessels have a certain fighting value: they are useful for coast defence, though their comparatively low radius of action and slight armament, comprising two torpedo tubes and proportionate torpedo-carrying capacity, somewhat restrict their spheres of action. After the commencement of hostilities, constructional speed was accelerated, and a further building programme laid down. Owing to the excellent building facilities possessed by the various British yards, submarines, even of the largest type, can be turned out very rapidly, and in this augmentation of the British submarine fleet Canada is playing a prominent part.

While the British submarine fleet is remarkable for its homogeneity, and, until recently, rigid adherence to one approved model, the French underwater fleet is somewhat more heterogeneous, though squadrons are preserved as far as possible. In France, the native inventor has always found the greatest measure of support, which, however, has been responsible for the creation of eight distinct types, each the product of an individual designer, though in one or two instances the design is an improvement upon a preceding model. The Laubeuf type prevails, however, especially in the latest building programmes. In France, moreover, the question of the most suitable type of engine for

surface propulsion does not appear to have been decided. Thus the improved Zédés are steam driven, while the Bellone, Chlorinde, and other types are propelled by Diesel motors.

Again, the French Navy has always divided underwater vessels into two classes—the submarine proper and the submersible. The former coincides with the British interpretation of the term, but the latter indicates a vessel which, upon the surface, bears, by its deck superstructure, a close resemblance to a torpedo boat, and is capable of submersion when desired, as already explained. The latest vessels compare favourably with those of Great Britain or any other Power. The larger vessels carry a complement of forty officers and men. Their torpedo armament is formidable, comprising both fixed interior tubes and adjustable exterior launching devices. The secondary armament for the most part comprises quick-firing guns.

The Russian submarine strength is greater than is generally supposed, twenty-eight such vessels being in commission upon the outbreak of war, while fifteen at least were under construction. But the Russian programme has been preserved with even greater secrecy than those of any other Power. Both the Holland and Lake types are represented, while, during later years, the ingenuity of a native designer, Bubnoff, has been appreciated, several vessels being built after his designs. Contracts for additional

vessels had been placed with the Krupp firm, previous to the outbreak of hostilities, but these vessels have been taken over by the German Government. For the most part they were of the small Germania type, though adapted to service in the Baltic Sea. The Russian submarine fleet is the product of the days since the Russo-Japanese War, and forms part and parcel of the comprehensive plan which was formulated to bring about the rehabilitation of the Russian Navy after the campaign in the Far East.

From time to time startling descriptions of a huge Russian submarine of 5,400 horse-power and 18,000 horse-power are related in the periodicals of the world. This virtually means a cruiser-submarine. But what is being achieved in this direction is unknown. All that is certain is that plans for such a vessel were prepared. In this, however, there is nothing remarkable, for Mr. Simon Lake, the inventor of the submarine which bears his name, submitted designs for a similar vessel as far back as 1904, but the conclusion of the war in the East rendered such a boat unnecessary. The report has received considerable credence from the fact that certain manufacturing establishments in the United States have supplied integral parts of machinery of special design, which, it is stated, were intended for a new and huge submarine which the Russian authorities had sanctioned, and which, in fact, was

in progress. But a submarine of 400 feet length and of the foregoing displacement and engine power is scarcely likely to materialise yet. The weakest feature is the proposed dependence upon electric motors for submerged travelling: nothing has yet superseded this form of propulsion for underwater movement.

Japan is so far distant from the scene of hostilities to-day that her submarine resources are liable to be overlooked. Our Eastern ally accepted this class of vessel during the war with Russia by importing five Hollands from the United States. These were of the same type as the first vessels built for Great Britain, being of 122 tons displacement and of 8½ knots cruising speed. Since those days, Japanese naval engineers have wrestled with the problem, while vessels have also been supplied by Messrs. Vickers, Limited, and from the Creusot yards of Messrs. Schneider et Cie, the French armament and warship builders. These latter vessels are of the Laubeuf type, displacing 520 tons upon the surface. They are fitted with cruising engines of some 2000 horse-power, which give a surface speed of about 17½ knots.

The entrance of Italy into the conflict swelled the submarine fleet of the Allies very materially, both numerically and in point of strength. The Italian underwater fighting fleet is composed of vessels of five distinctive types, comprising the Bernardi, Cavalini, F.I.A.T., Laurenti, and the

Krupp Germania. The latter, however, is a small vessel, being a sister-ship to the majority of the *unterseebootes* of the German Navy, in which the Essen firm has specialised somewhat extensively. The Italian type which has proved the most successful is that evolved by Major Cesære Laurenti, and built by the F.I.A.T. Company. This vessel belongs to the submersible category, submerging upon an even keel and having a ship-shape deck superstructure. It is of strong construction and has proved an excellent sea-going type. The construction attracts attention by the manner in which the subdivision of the hull is arranged. The boat is divided into at least eight watertight compartments, which contribute very materially to its safety. This was conclusively demonstrated upon one occasion during manœuvres. One of the boats, when running submerged, sprang a leak, a defective valve being the cause of the trouble. Instead of coming to the surface to repair the defect, the commander shut off the engine-room, so that the danger from the leak became isolated. The vessel completed her appointed evolutions, but when she finally returned to port and the engine-room was opened, it was found to be flooded with about one ton of water.

In common with the boats of the other Powers the early Italian submarines were fitted with high-speed explosion motors, depending upon the volatile

fuel, benzine. But the F.I.A.T. Company devoted its attention to the heavy-oil or Diesel engine, and succeeded in its efforts to such a degree that the benzine motor was definitely abandoned. This development proved of distinct advantage, since the lines of the Laurenti craft are such that they can carry larger and more powerful surface engines than is possible upon a similar displacement with boats of the more conventional form. The vessels are built to submit to a submerged test ranging from 150 to 175 feet, while the pumps handling the water ballast are sufficiently powerful to discharge 130 tons of water per hour at a depth of 130 feet. The vessels are fitted with three propellers, the central propeller being utilised for cruising in the "light" condition, and they are normally driven at full power. This arrangement, it is claimed, gives the vessel an extreme radius of action, as it can be driven at the most economical speed—8 knots.

When one turns to the Central European Alliance, the submarine situation is far more obscure. For many years Germany did not seriously entertain the submarine. The *U1* was launched in 1905, but it was essentially an experimental vessel. From the first the German boats occasioned interest by reason of their equipment with heavy-oil engines. But the construction of the modern German underwater fleet may be said to date only from 1910, since the seven vessels which followed the initial

experiment were complete failures. In order to fulfil the desire for high speed, efforts were made to crowd machinery into a hull of light construction and displacement, with the obvious results.

Suddenly, however, Germany appeared to realise that she was lagging behind the other nations, especially those with whom conclusions would have to be tried some day. Accordingly, a comprehensive and progressive submarine building programme was elaborated, coincident with the report that the Krupp firm had succeeded in perfecting a new type and was in a position to carry out construction at Kiel upon a more extensive basis. This programme arranged for the completion of seventy-two vessels by the year 1917.

For some unknown reason the rate of construction failed to be maintained, since, upon the outbreak of war, there were only twenty-seven submarines available, of which seven were either of no value or could be used only for the defence of ports and rivers owing to indifferent seaworthiness. It was anticipated, upon the declaration of war, that eleven additional vessels would be ready for service by the end of February 1915, bringing the fleet up to thirty-six all told. Naturally, in the meantime, desperate endeavours were made to reduce the disparity in the size and strength of the submarine forces of the belligerents, new keels being laid down on every available slip.

But was adequate allowance made for the wastage which necessarily attends a great war? How many German submarines have been sent to their last account? The most satisfactory, and incidentally the most reliable, indication of the German submarine situation is to be obtained from German sources. At the end of February 1915 Germany would have possessed thirty-six submarines *if there had been no losses!* About that time *U47* went through her official trials. Now, the German practice is to number their submarines consecutively, as they are commissioned, the prefix signifying *unterseeboote*, of which word it is the initial letter. But the appearance of *U47* did not bring the fleet up to that number: it even fell short of thirty-six! In other words, the eleventh boat beyond the contemplated number, which was then under trial, brought the active fleet to fewer than thirty-six submarines.

Now, from this specific Teuton statement, it is only possible to infer that the German submarine losses have been somewhat heavy—far heavier than is generally supposed—and, up to the appearance of *U47*, twelve must have disappeared, because the commissioning of this vessel did not bring the fleet to thirty-six ships. This, despite the fact that all vessels under construction for foreign powers were taken over.

The question thus arises—Does the German

Government honestly admit its submarine losses? On this point there is considerable difference of opinion. The war is being waged behind a veil, so why should a loss be admitted, unless the act is witnessed by a third party, such as a passing vessel? Dead men tell no tales, and the significant fact remains that in many instances a submarine is lost with the whole of its crew, so that there is no possibility of a survivor's report.

Of course, at the same time, one must not forget that the German submarines are no more immune from unknown accidents than those of other nations. The British *AE1* was lost mysteriously in the Pacific; German submarines may have disappeared in the same way. Germany is striving strenuously to build up the strength of her submarine fleet; keels of many vessels have been laid down, and construction is being feverishly pushed forward; but a modern submarine takes as long to build as a destroyer, if not longer, owing to the more intricate character of the machinery. Prior to the war, the submarine construction programme was entrusted to the Germania yards: it was a Krupp monopoly. But Krupps, upon their own admission and despite the facilities they possess, cannot possibly turn out more than a handful of submarines a year. Of course, under the stress of war, the plans of submarines would be distributed among the many shipbuilders. Germany has over 100 building slips

which could be adapted to this purpose, but other vessels, of which she is sorely in need, would have to be sacrificed. Then it must be borne in mind that many of the slips are not adapted to the construction of other than small coast-defence craft.

The situation is aggravated from the circumstance that it is not a mere matter of turning out so many vessels of a specific type. There is no standardisation in submarine construction. Progress is too rapid; the respective Powers are striving might and main to outdistance one another. In matters pertaining to submarine design and character, Germany is lagging some three to four years behind the Allies, and, although the exigencies of war will enable this leeway to be reduced appreciably, the fact must not be forgotten that the Anglo-Franco-Italian submarine builders are advancing at an equally rapid rate, so that the lead may be preserved.

Germany is additionally handicapped in the point of labour. Previous to the outbreak of war the number of men employed in the shipbuilding industry was about 130,000. Assuming that this industrial army has not been depleted to meet the requirements of the military, it would still be insufficient to enable Germany to maintain an extensive building programme at high pressure for a very prolonged period. The German shipyards are splendidly equipped with mechanical appliances, for

experience speedily proved that the German labourer cannot compare with the British in physical stamina and endurance. But mechanical appliances, to accomplish the desired end, must be adequately supplemented by human resources, and it is in the human factor that Germany suffers. At the time war was declared considerable new construction for the mercantile marine was in progress, and all this work would have to be completed to the launching stage so as to enable the slips to be cleared for submarine building. Furthermore, rapid construction is dependent upon the steady and continuous supply of raw material, which not only involves the production of the requisite steel and other metal work, but also the transport of the same to the various yards.

So far as the second contributory power to the Central European Alliance is concerned, she is in a far worse plight. The Austro-Hungarian submarine fleet numbers only eleven vessels, of which six are under 300 tons submerged displacement, while the remainder range up to 520 tons. The fleet as a whole is vastly inferior to that of Italy, while its personnel is a doubtful quantity. Austria has relied entirely upon foreign builders for submarines, and the vessels comprise the Lake, Holland and Germania types, the latter predominating.

Upon the outbreak of war the belligerents mustered approximately 204 submarines, of which 167 were

flying the flags of the Allies. This force was supplemented later, when Italy threw in her lot with the Entente, by some twenty-four Italian vessels. Austria and Germany mustered thirty-seven craft, but, as explained, not all of these were available for service. It will be noticed that although the advantage is preponderatingly in favour of the Entente Powers, it has so far proved of little material value. There are no hostile vessels, naval or mercantile, against which they can demonstrate their capabilities. But the existence of the formidable British underwater fighting forces has revealed to Germany her own impotence upon the water. Curiously enough, the very havoc she has wrought among British shipping has brought home to her the great danger in which she stands. Her High Seas Fleet certainly dreads the British array of surface fighting craft, but it goes in terrible fear of the submarine fleet. Germany knows full well that when her navy ventures into the open it will be assailed in all directions by Britain's underwater force; her own achievements with the torpedo have conveyed some idea of what to expect.

CHAPTER XX

THE LIMITATIONS AND THE FUTURE OF THE SUBMARINE

No engine of destruction entered the arena of the greatest war under such a cloud of uncertainty and speculation concerning its possibilities as the submarine. It was an unknown quantity, an untried weapon, an arm which was to be passed through the mill of exacting application for the first time. Evolutions and manœuvres with underwater fighting ships conducted during times of peace under conditions approaching, as closely as possible, those of actual warfare, had been carried out by the respective Powers, and had established certain potential factors in a conclusive manner. At the same time, however, weaknesses and shortcomings had been revealed with equally striking emphasis. While the precise and relative character of these advantages and limitations were jealously guarded in the respective official circles, conjecture and fantastic imagination were busily engaged in the endeavour to satisfy a curious public.

Generally speaking, the submarine, as a fighting machine, has excelled the most sanguine anticipa-

tions of those who were in the position to know, as a result of the knowledge gleaned from manœuvres, just what the underwater fighting ship could and could not do. The factors of reliability, mobility and aggressiveness have been brought out with extraordinary force. Likewise the one weakness has been revealed with an emphasis which scarcely was expected.

While Britain was experimenting with submarines, and the Admiralty had expressed its determination to become possessed of a potential submarine fleet, many critics contended that it was an erroneous policy. This opinion was expressed more powerfully as the years passed, when it was patent to the world that the conflict of the future would be waged between the Entente Powers and the Central European Alliance. The trend of the argument was that, as Britain had attained the position of being able to command the seas, submarines were of no fighting value to her. They were purely and simply the weapon of the Power that was desirous of wresting sea supremacy away from Britain. The submarine was essential to Germany, because with an adequate fleet of these craft she could assail and attack the British Navy, meanwhile keeping her own fleet in harbour until the policy of attrition had been continued to such a degree as to offer the German Navy a possible chance of offering battle with success.

It was a specious line of reasoning, but, like every other argument raised during times of peace, has been torn to shreds by actual experience. Attrition by submarine attack has been attempted by both sides, but so far has not been carried to any definite conclusion. The German fleet, as expected, keeps behind its mines and under the cover of its fortifications in order to be safe from submarine attack; the British fleet keeps well away from German waters, where there is plenty of sea-room, for a similar reason.

The German achievements with the submarine, at all events during the opening stages of the war, were due to a combination of unexpectedness, lack of familiarity with such fighting methods, and luck, the last-named factor predominating.

As an attacking force, the submarine has proved its impotence when adequate combative measures are adopted. During the British warship attack upon the German artillery strewn along the coast of Flanders the German submarines attacked time after time, not in the manner of sporadic individual raids, but by sustained aggressive tactics in force. The conditions were eminently favourable, because their bases were within close proximity for the replenishment of supplies, fuel and ammunition. Torpedoes were expended lavishly, but not one of the British scrap-heap warships which participated in the bombardment fell a victim.

It has been maintained, during the past three years, that submarines and their work would follow two distinctive lines; but the experience of war has established that the lines are much wider apart than ever was expected. The one class is the home-defence vessel of some 300 tons, having a cruising radius of about 1000 to 1,500 miles. These boats are efficient, so far as they go, throughout a radius of 400 miles from port, and, as results have proved, can wreak considerable damage among fishing vessels, and can harass cross-Channel traffic. But their low speed is against them: by ruse and subterfuge alone are they able to get a torpedo home.

The ocean-going submarine is on a different plane. It is able to carry its campaign into distant waters, though compelled to act upon its own initiative, and to trust to a large extent to luck. Here, again, speed is an adverse factor, both when it is cruising and when travelling submerged. When pushed, it can compare fairly favourably with a modern freighter of medium speed, but it cannot sustain the effort for a very long period: the oil engine lacks the flexibility possessed by its steam rival.

When the foregoing type of submarine made its appearance, it was classed as a "fleet-going" type of submarine, meaning thereby that it was designed for operation with the main fleet. But a little reflection suffices to establish its limitations in this class of work. The efficiency of any squadron is

governed by the speed of its slowest vessel. Now, if one of these submarines be attached to such a squadron, whether it be cruiser or battleship, it will affect the tactical value of the latter to a serious degree. Of what avail is it to build surface vessels with speeds of 21, 24, 26 or more knots, if, when the critical moment arises, such vessels are unable to move at a speed exceeding the maximum of the accompanying submarines, which, at the moment, even with the latest underwater craft, is not more than 16 to 18 knots? It deprives the squadron of its vital element—the speed gauge, whereby it is able, if it is faster than the enemy, to determine at what range it shall offer action.

From time to time sensational reports are published in the press concerning the speed of new submarines, comparing their performances in this direction with those of a destroyer. Seeing that the latter of current design can show a turn of 30 knots or more, the comparison is fantastic. The ordinary individual cannot see any logical reason why a submarine should not have the speed of a destroyer, but the submarine engineer knows full well that such a speed has not been attained with an underwater vessel, and in the light of current knowledge is almost impossible. Destroyers possessed of a speed of 30 knots are about the same length as the latest type of submarine, and displace about 800 tons. Into a relatively light hull engines

capable of developing some 20,000 horse-power are crammed. The displacement of such a destroyer is approximately identical with the latest German submarines, but the engines of the latter develop only 4000 horse-power—about one-fifth of that carried by the 30-knot destroyer. Consequently, it will be seen that the engineer has a considerable distance to travel along the road of development before the 30-knot submarine—the figment of an imaginative brain—is brought within the range of practicability. To produce such a high-speed surface craft was a simple task in comparison with that which confronts the realisation of a submarine of equivalent pace, especially when one recollects that a second installation of machinery for underwater propulsion has to be carried as well as a maze of other mechanism. In the construction of the submarine, considerations of space and weight affect the issue very materially.

At the present stage of its development the submarine cannot be regarded as a naval fighting unit in the general interpretation of the term. By reason of its severe limitations of speed it cannot act with a battle squadron. So far as present experience has carried the subject, the underwater naval vessel is restricted to one sphere of activity—raiding. Here, again, there are limitations. The ocean-going submarine, compelled to make long journeys between its base and the scene of projected operations, there

to lie in wait to catch what turns up, is far from being comfortable to the crew. The quarters are necessarily confined. Although considerable attention has been devoted to habitability, the underwater fighting ship cannot be compared in this respect to its surface travelling escort. This deficiency is certain to exercise its effect upon the members of the crew; to undermine their fighting powers.

In this respect, the Germans are in an unenviable plight as compared with the British crews. The German submarine has to steal through or under the blockading cordon of British vessels, if it can, and hurry away from the patrolling lines. No parent ship or tender dare accompany it, because it would never pass the strangling line of British vessels. On the other hand, the British submarines, being compelled to operate in a somewhat limited radius of action, owing to the confinement of the German fleet, are able to move with their tenders which carry relief crews. Consequently the British submarine can be kept manned by fresh men and thus is maintained constantly at the top-notch of fighting efficiency.

The German submarines are suffering severely from the effects of the British blockading tactics; their crews are being slowly but surely demoralised, as their savagery illustrates; the strain is too exacting to be withstood indefinitely. The ocean-going submarines are equpped for two months' cruising,

but the average stay away from port varies from three weeks to one month, and upon their return the distressed physical condition of the crews has been a subject of considerable German comment. In no other phase of naval activity is the necessity to change the crews frequently so imperative as with the submarine; that is, if the latter is to be kept up to the fighting pitch.

As the war drags along, the Germans are realising that the submarine, like the much-vaunted airship, is somewhat in the character of a faith-cure. In distant waters their activity has almost ceased. So far as the North Sea is concerned it is certain to produce a harvest, since those waters are still busy with British shipping. But the naval importance of the German submarines has dwindled almost to insignificance. The inaction of the High Seas Fleet prevents all accumulation of knowledge concerning the co-operation of the submarine with surface craft under battle conditions. The British authorities, on the other hand, are carrying out manœuvres of this character every day, and, what is more to the point, the knowledge gained from actual experience, in the brushes with the German fleet, is being put into practice. In other words, the British Admiralty knows exactly what rôle the submarine can fulfil in tactical evolutions, while the German Admiralty is in ignorance: their armchair theories and paper plans remain to be tested.

But the impotence of the German submarine fleet can be demonstrated in another and more graphic manner. Every ocean highway throughout the world is open to the vessels of the Allies. The English Channel is bridged at several places by ferries of steamships swinging incessantly to and fro, bearing men, munitions and supplies to the army in France. The movement of French troops across the Mediterranean has proceeded just as smoothly and as uneventfully. Troopships laden to the water's edge have sailed from Australia, New Zealand, Canada, India, Africa, to the Dardanelles, Great Britain and France. Every steamship lane criss-crossing the seven seas is a line of communication to the Allies. Yet only a few vessels engaged in this specific military duty have fallen victims to German submarines!

And what of the future? Will the submarine undergo further development, or will it lapse into the limbo of things that were, as it did a century ago, to suffer a further revival at a distant date? So far it has accomplished little of importance. Vivid pictures of what will happen to Great Britain when German submarines infest British waters by the score have been painted, but the fact has been overlooked that the more submarines to be stalked, the greater will be the bag, while experience has proved to Britain that she can effectively curtail such operations. British attention is being concentrated upon com-

bative and antidotal operations, a question which, up to the present, has not had to be considered by Germany, but which will demand attention in due course. There is every indication that a complete means of rendering the submarine impotent will be perfected before the war has run its length, and this circumstance has served to extend additional support to the theory that the submarine as it is known to-day will be superseded.

The goal towards which all engineers are striving is the perfection of a submarine having a surface speed of 25 knots, an economical cruising radius of 10,000 miles, a submerged speed of 20 knots at least, and a far more formidable armament than that borne to-day. To ensure the fulfilment of these specifications within a reasonable space of time, some sensational discovery or startling new development is imperative. The dual system of propulsion must be superseded; at any rate, electric propulsion underwater will have to be abandoned, since it acts as a brake upon further development. The perfection of a propelling system common to both surface and submerged movement will exercise the greatest influence upon further progress, for it will necessarily affect the difficult questions of dimensions, weight and space. If every inch of available space has to be devoted to the engine-room of a destroyer, in order to attain a speed of 30 knots upon a light displacement and in a vessel of relatively

small dimensions, how much greater are the sacrifices which will have to be made to bring the submarine into line with its deadliest foe? The term engine-room is used in its broadest sense, since it includes a maze of auxiliary machinery, as well as fuel bunkering.

It has taken fifteen years to double the surface speed of the submarine—from 8½ to 17 knots. This achievement has meant an increase on the propelling machinery of 1,250 per cent.—from 160 to 2000 horse-power. The radius of action has been raised from 300 to 5000 nautical miles, while the displacement has risen from 122 to 1000 tons.

It will thus be seen that the designer of the submarine is confronted with some pretty problems in the realisation of his dream of a 25-knot vessel. Speed demands power, and power costs money. That is the eternal wail of the naval engineer. Whereas 2000 horse-power is productive of a speed of 17 knots, the addition of a further three knots to this speed means an extra 3000 horse-power: engines capable of developing 5000 horse-power—2,500 horse-power per shaft—must be installed. The raising of the speed to 25 knots will therefore necessitate the cramming of at least 12,000 horse-power within the hull. It must be remembered, too, that the length and displacement of the modern submarine is equal to the length and displacement of the latest type of destroyer. But, in order to

carry machinery developing 12,000 horse-power on the surface, as well as the ordinary electric propelling plant for submerged action, the speed of which must also be increased, it will be necessary to build a larger and longer hull of heavier design, involving an increase in weight and displacement.

Nor does the matter end here. As dimensions and displacement are augmented, the time occupied in the submergence of the craft necessarily increases, and, in the light of present knowledge, some eight to ten minutes would be required to submerge a 25-knot submarine. This renders the submarine additionally vulnerable to destroyer attack, so, in order to ensure the complete protection of the submarine during the transition from the cruising to the submerged condition, it will be necessary to armour the upper part and conning tower sufficiently to defy direct fire at short range from 4·7 inch guns, while the submarine will have to be equipped with weapons of equal calibre, at least, in order to hold a destroyer at bay during the process of submerging.

But when the 25-knot submarine first occupied the attention of engineers, the average speed of battleships operating in the Grand Fleet was approximately 22 knots. It was urged that by accelerating the speed of the submarine to 25 knots there would be an advantage of 3 knots in favour of the underwater ship. Unfortunately for the submarine designer, the question of speed in regard to the capital

ship has taken a startling turn, as the result of the coming of the *Queen Elizabeth* class.

The situation at the moment recalls that long ding-dong struggle which has ensued between the armour-plate manufacturer and the builder of the big gun. The uninformed cherish the opinion that the problem of the underwater fighting ship has been solved; the submarine naval engineer knows better. To him the solution of the issue is as remote as ever; his troubles and labours are only just becoming manifest.

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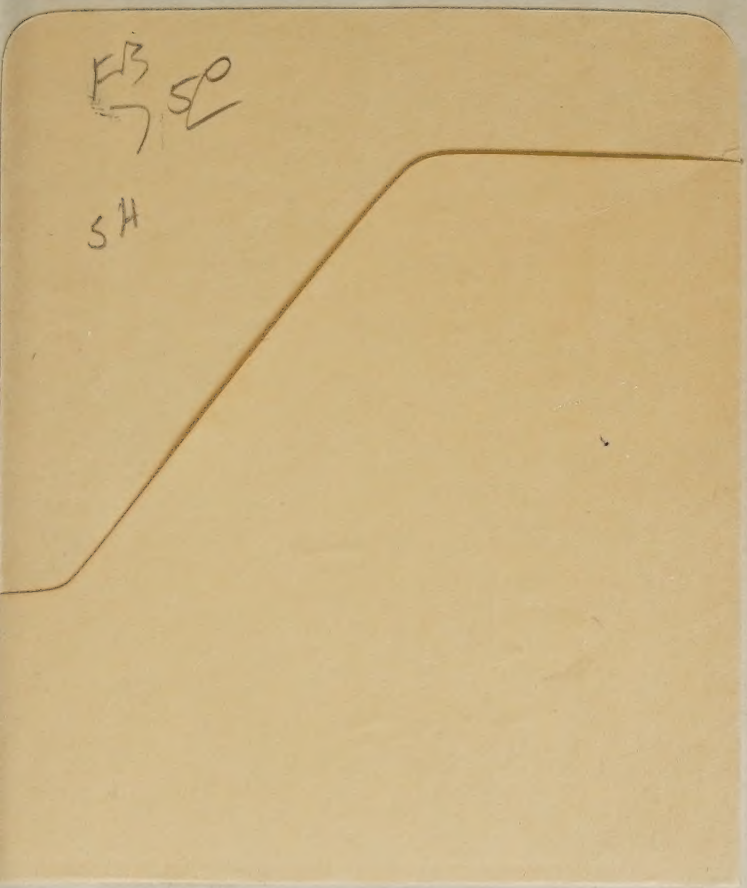
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